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Geology of the Annapolis Area, Iron County, Missouri

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GEOLOGY OF THE ANNAPOLIS AREA
IRON COUNTY, MISSOURI

BY

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THESIS

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I. INTRODUCTION

1. Location of Area

The thesis area is located in Southeast Missouri on the southwest side of the St. Francis Mountains and in the southern portion of Iron County (see figure 1). The western boundary lies on the Reynolds County-Iron County line. The eastern boundary lies on the Iron County-Madison County line. On the Des Arc Quadrangle map the area includes sections 8 to 36, 31N-3E, sections 7 to 36, 31N-4E and sections 3 to 5, 30N-3E (see map 1).

The area may best be reached from the north by way of Highway 49.

2. Shape and Size of Area

The area is rectangular in shape and consists of 58 square miles.

3. Culture

There are two towns within the boundaries of the thesis area. Annapolis, which is located in the center of the western half of the area, is the largest of the two, and has about 490 inhabitants. Minimum constitutes a very small settlement in the northeast corner of the area.

Indians at one time inhabited the area since an old burial ground is located near the railroad at the center of west side- NW¼-SW¼ 11 31N-3E. Mr. Herman, on whose land the burial ground is located, has found numerous arrowheads. A few of these are shown in figure 3.

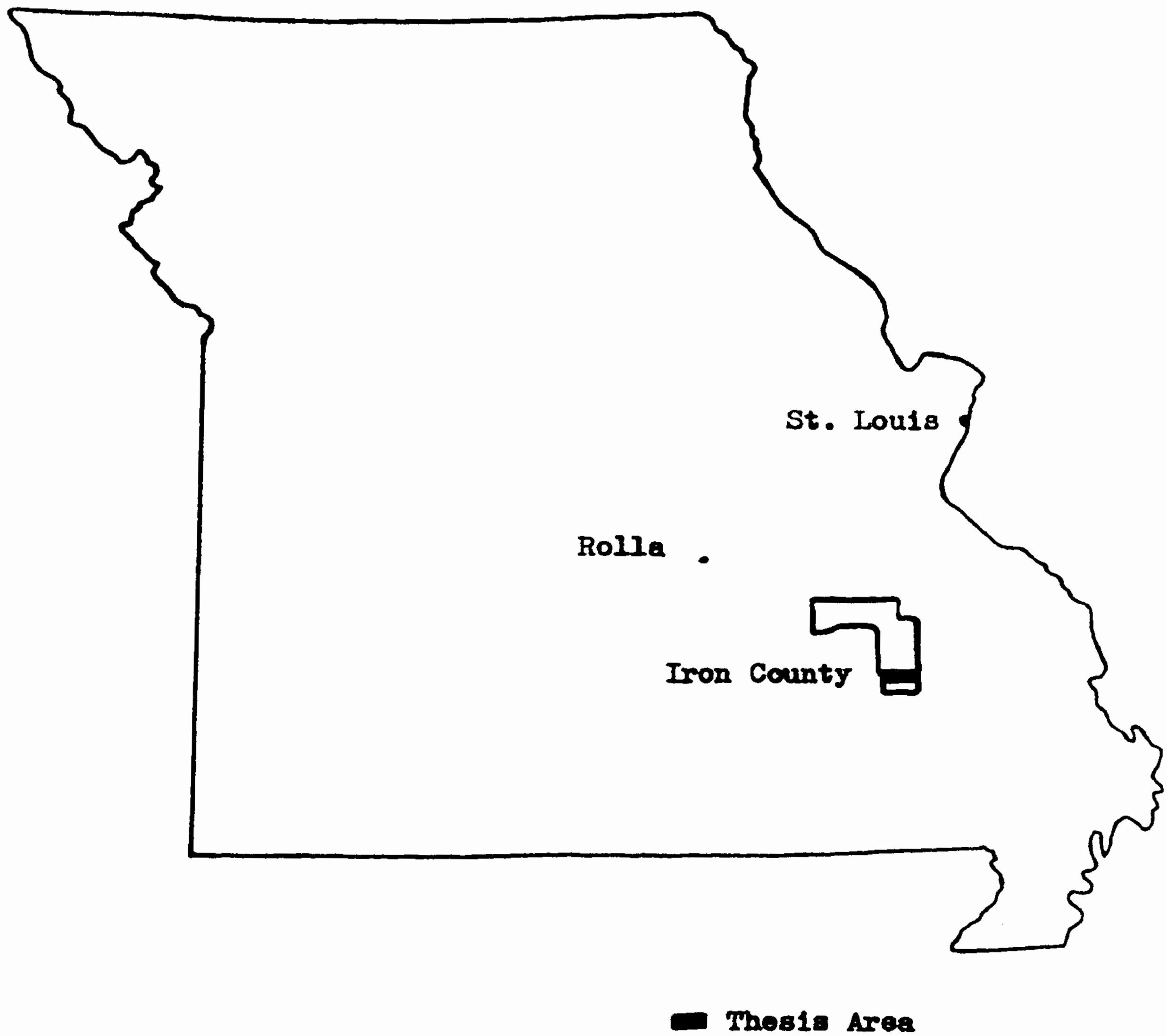

Figure 1. Map of Missouri showing location of thesis area.

Figure 2. View from Stony Mountain looking west toward Annapolis.

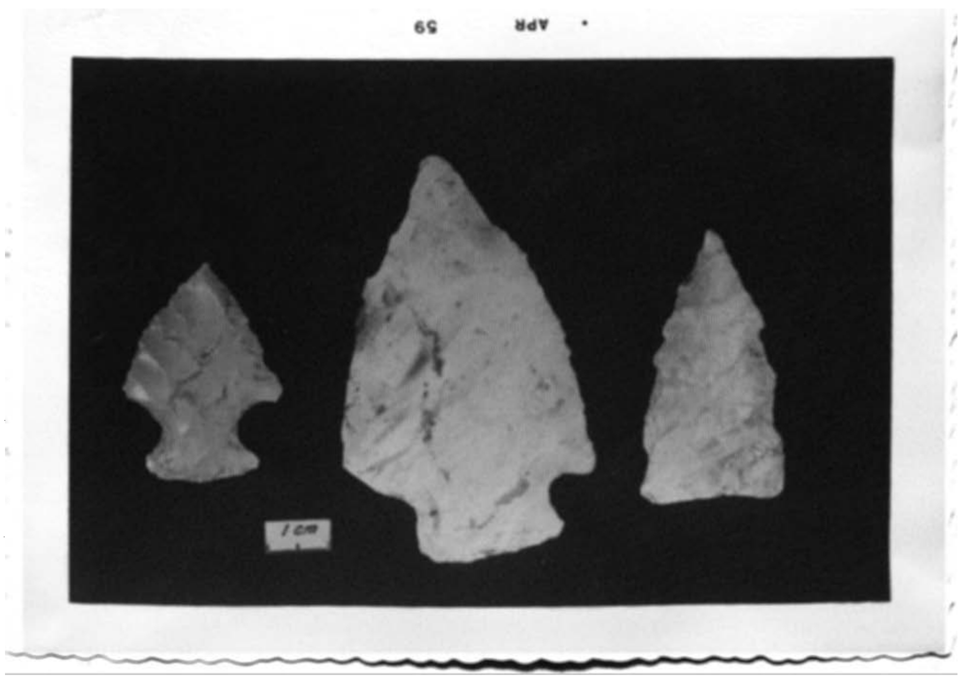

Figure 3. Arrowheads from an old Indian burial ground located near the railroad at the center of west side- NW¼-SW¼ 11 31N-3E.

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Occupations- Most of the people are engaged in timbering, livestock raising and farming.

The farms are situated mostly in the bottomlands along the creeks.

A small grist mill which makes corn flour, employs a few people. The mill is located about one-half mile north of Annapolis on the east side of Big Creek near the center of section 15.

About five people are employed at the Duncan Brothers' agricultural limestone quarry. The quarry is located one-half mile north of Vulcan, Missouri on the hill on the east side of Big Creek in SE corner 36, 31N-3E.

In the past, many of the people in the surrounding area worked for the Annapolis Lead Company, while the mine was still in operation. Mining went on from 1923 until 1942.

Roads- State Highway 49, which passes through Annapolis, is the only paved road.

There are three County highways in the area. These include Highways C, F and K. All three are improved gravel roads.

Highway C runs east from Highway 49 about one-half mile east of Annapolis. Fredericktown may be reached by this route, or by taking the road at Minimum which connects Highway C with Highway E to the north.

About one-half mile south of Highway C, Highway F also runs east from Highway 49 and roughly parallels Highway C for about five miles. It runs into Highway C at Minimum.

Highway K runs west from Annapolis and follows Bear Branch Creek. Lesterville, in Reynolds County, may be reached by this route.

Other dirt and gravel roads include those along Brushy Creek, Richland Creek, Funks Branch, McGue Hollow, and the Mine Hollow.

Old timber roads and trails follow the tops of most of the hills along the divides.

Creekfords- Creekfords occur along many of the roads where they cross creeks. The largest creekford occurs where Highway F crosses Crane Pond Creek in the southeast part of the area. The road at this creekford was found to be impassable several times during the summer.

Bridges- There are two concrete bridges in the area. One is on Highway K and crosses Big Creek about one-quarter of a mile west of Annapolis. The other is on Highway C and crosses Crane Pond Creek at Minimum.

Railroads- The Missouri Pacific Railroad, which passes through Annapolis, is the only railroad line through the area. It goes to the north through Ironton, and to the south through Piedmont.

Dam- A dam is located in Big Creek beside the grist mill (see "Occupations").

Lookout tower- A fire lookout tower is located at the top of the hill in C-W½-NE¼ 4 30N-3E near Vulcan.

Power line- A power transmission line passes through the western half of the area. It trends due north from Annapolis.

Just north of Annapolis it swings to the east for about a mile. It then swings south and resumes a N-S direction.

4. Purpose of Investigation

The objectives of this investigation include the following: (1) to map the distribution of the igneous and sedimentary rocks, (2) to investigate the structure and lithology of these rocks and to determine their sequence, (3) to determine the stratigraphic position of the sedimentary rocks relative to known Missouri formations, (4) to determine the igneous rock types, and (5) to investigate the distribution and occurrences of economic minerals.

5. Method of Investigation

Three months were spent in the field on mapping and outcrop studies. The field work was alternated a few weeks at a time between igneous rocks and sedimentary rocks. Laboratory work consisted of making petrographic studies on the various igneous rocks. Rock types and special features were determined and analyzed.

One of the first steps that was taken was to outline the exposed igneous rock areas, by the use of aerial photos.

The field work consisted, for the most part, of making detailed field examinations and descriptions of the outcrops. Usually a day or two was spent on outcrop reconnaissance over several square miles. The outcrops were then revisited and examined in detail. This system was repeated in a new area every one or two weeks.

As the work progressed, certain lithologies and sequences became known. These formed the various lithologic units which are shown on the map.

Numerous valleys, hills and hollows occur in the area, making it rather easy to locate points on the map. Aerial photos were taken to the field on a few occasions. The Brunton Compass was also used to locate points by taking bearings on different landmarks.

An altimeter was used to determine absolute elevations, usually for about one or two hours after setting. The altimeter and Brunton Compass were used for measuring thick sections. The tape was used for detailing sections.

Hand specimens were taken in the field for making thin sections. Forty-two thin sections were used for determining the igneous rock types. All forty-two of the sections were etched with HF and stained with sodium cobaltinitride for detecting orthoclase. The technique is described in HEINRICH[1] (1956, p. 8).

Samples for insoluble residue studies were taken from several sections. Mr. McCracken, geologist, of the Missouri Geological Survey, examined the samples. The results of these samples have been used for correlation purposes with known Missouri formations.

Before the actual field work began, trips were made with Dr. Hayes, Assistant State Geologist, of the Missouri Geological Survey, to various localities in Southeast Missouri where

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1 All references are in the bibliography.

formational type lithologies occur. These areas were also revisited on several occasions during the summer with Dean Weixelman. (WEIXELMAN (1959) mapped the northeast portion of the Des Arc Quadrangle at the same time that the field work was being done for this thesis around the Annapolis area.(see bibliography).

6. Previous Work

Previous work consists of literature, maps, aerial photos and well logs.

Previous literature and maps include work on both the igneous and sedimentary rocks.

The igneous rocks were investigated and mapped by HAWORTH (1895) and ROBERTSON (1949). HAWORTH'S work included mapping the entire crystalline rock area in Southeast Missouri. He mapped the rocks around Annapolis under his main division of rhyolites. HAWORTH (1895, p. 184, 191, 194, 198, 204, 208) noted the presence of large microcline phenocrysts and spherulitic texture in the piedmontite bearing porphyry just south of Annapolis. He also noted flowage texture in the vitrophyre near the summit of the porphyry hill east of Annapolis.

ROBERTSON (1949) began work on the sequence of the felsites in Southeast Missouri. According to ROBERTSON, there are three different felsite flows in the Annapolis area, but the age relations between them are obscure. The three flows include the Annapolis Felsite, the Chocolate Brown Rhyolite and the Red Rhyolite.

The sedimentary rocks were studied by DAKE (1930, p. 105) and KIDWELL (1947). DAKE'S work was of a reconnaissance nature. He states that a Bonneterre-Potosi contact is present at the surface both north and south of Annapolis.

KIDWELL (1947) made a preliminary study and a geologic map of the Annapolis area. His map shows the Davis and Derby-Doerun formations exposed at the surface. The mapping was aided by results from studies of insoluble residues from 20 measured sections along Big Creek Valley.

The area has been mapped topographically, and forms the central portion of the Des Arc 15 minute Quadrangle map. The area was surveyed in 1926. The first edition of the map was published in 1929 by the U.S.G.S. The topography is by Hughes, Overgreen and Hope. The map was reprinted in 1946 with corrections.

Aerial photographs cover the entire area. Parts of the area were flown in August, September and October of 1955. They are available through the Commodity Stabilization Service in Kansas City.

Thirty-nine well logs and 20 logs from measured sections at the surface were made available by the Missouri Geological Survey. All of the well logs except three are from wells in the vicinity of Annapolis. The three well logs are from the eastern portion of the area. The 20 measured sections are located at various points along Big Creek valley.

These logs are based on studies of the gross lithologies and insoluble residues of the samples.

The St. Joseph Lead Company has made available the elevations of the supposed Bonneterre-Davis contact from 62 wells in the western portion of the area around Annapolis and along Big Creek. The total wells logged by the St. Joseph Lead Company in the western portion of the area far exceeds this number.

II. GEOGRAPHY

1. Relief and Elevations

The maximum relief in the area is about 716'. The highest point in the area is at the top of Grassy Mountain. The elevation at this point is 1196' above sea level. The lowest point in the area is at the bottom of Crane Pond Creek in the southeast portion of the area. The approximate elevation at this point is 480' above sea level.

The average relief between valley bottoms and hilltops is about 250'.

Most of the area lies at elevations between 600' and 850' above sea level. There is a general increase in elevation from southeast to northwest.

2. Topography and Drainage

The broad features of the surface include two main NNW-SSE trending stream valleys (Big Creek and Crane Pond Creek) with drainage to the south. The two valleys are spaced about five miles apart. A broad, elevated, dissected area with a similarly trending ridge occurs between them. This ridge forms the main divide through the area. It extends from the Big Creek-Crane Pond Creek join in the southeast part of the Des Arc Quadrangle to the point where it forms the Big Creek-Marble Creek divide in the north central part of the quadrangle. A second divide, trending in a similar direction, occurs in the northeast part of the area. To the north it likewise forms the Big Creek-Marble Creek divide. A third ridge, occurring in the southwest part of the area, also trends in a NNW-SSE direction. This divide lies between Big Creek and Black River. It is also part of the main divide between the Black River to the west and the St. Francis River to the east.

Locally, hills are formed between the tributaries of Big Creek and Crane Pond Creek. The topography is characterized by steep, somewhat isolated knobs, and long winding ridges. Steep, forked hollows cut into the ridges in many places.

The highest hills occur where igneous knobs are exposed. Steep sedimentary bluffs occur in places along the main creeks, giving evidence of an early stage of stream cutting and rapid erosion. Erosion, however, is still not keeping pace with solution of the carbonates, since most of the hills are heavily underlain with residuum.

The drainage pattern is somewhat dendritic. In many places creek courses are altered by exposed igneous rocks and hard sedimentary bluffs. Peripheral drainage occurs around exposed knobs. Locations showing such are as follows: (1) sec. 27 31N-3E and (2) sec. 26 31N-4E. Peripheral drainage occurs around hills of residuum. Such drainage is apparently influenced by subsurface igneous knobs. One such locality showing this is at sec. 33 & 34 31N-3E.

3. Vegetation

During the summer the hills and valleys are almost entirely blanketed with vegetation (see figure 2). The area, for the most part, is thickly overgrown with young trees and underbrush. During the past, most of the big trees were cut down for timber. According to one old-timer, big pine trees once covered much of the area.

Large open grassy areas often occur along the sides of exposed igneous knobs. Sometimes the areas are belt shaped and trend part way around the knobs. Sometimes they alternate up the knobs with similarly shaped tree covered areas. This is apparently due to weathering which is influenced by structures resulting from flowage. The same kind of grass appears to occur in most of these grassy areas.

4. Rock Exposures

Compared with the whole thesis area, the exposures of igneous rocks represent about 10%, the sedimentary rocks only about 3%.

Most of the igneous rock exposures occur on the knobs in the hilly portions of the area. Some exposures occur along the creeks in the low lands, as for example in various places along Crane Pond Creek.

The sedimentary rocks are distributed in and along creeks and intermittent streams. They occur as bluffs of various thicknesses along the creeks and valleys.

III. STRATIGRAPHY AND PETROGRAPHY

Outcrops in the thesis area show only igneous and sedimentary rocks. No metamorphic rocks were observed or reported in drill holes.

Previous work in the St. Francis Mountain area shows that the sedimentary rocks lie unconformably on the igneous rocks. No igneous intrusions, dikes, extrusions, etc. were observed in the sedimentary rocks in the thesis area.

The igneous rocks are older than the sediments. They are extrusives and consist of porphyritic rhyolite. Diabase intrudes the porphyry at one locality. These rocks are apparently Precambrian in age. BRIDGE (1930, p. 59) states that the base upon which the igneous rocks rest is not known, and therefore their total thickness cannot be measured. The relief of the Precambrian in places in the area under investigation ranges up to 1000' with porphyritic rhyolite occurring at the Precambrian surface. The rhyolites may therefore be considered to be at least 1000' thick.

The sedimentary rocks consist predominantly of dolomites. The thickest section in the thesis area occurs in SE¼ 31 31N-3E. The section here is from 700' to 800' thick. These rocks are Upper Cambrian in age.

The following is the sequence and thicknesses of the Upper Cambrian formations which are exposed in Southeast Missouri (as reported by STEWART, 1944):

Formation	Thickness (feet)
Eminence	0-270
Potosi Dolomite	0-300
Derby-Doerun	0-170
Davis Formation	0-100
Bonneterre Dolomite	0-500
Lamotte Sandstone	0-500

1. Precambrian Igneous Rocks

The igneous rocks include porphyritic rhyolite and one occurrence of diabase.

a. Rhyolite

The rhyolites have been subdivided in this investigation into four main varieties. The subdivision has been made on the basis of variations in megascopic and microscopic characteristics. Megascopic characteristics include color of the rock (colors range from blue to red to brown to black and are apparently due to the combined effects of the relative concentration of orthoclase, degree of fineness and composition of the groundmass, and the presence of epidote and iron oxide), relative size and amount of phenocrysts and flow structures. Microscopic characteristics include relative grain size of the groundmass and flow textures. The four varieties include the following: (1) black porphyritic rhyolite (Annapolis Felsite of FORBES ROBERTSON, 1949), (2) brittle, purplish black rhyolite, (3) reddish brown porphyritic rhyolite with large feldspar and quartz phenocrysts and aphanitic groundmass, (chocolate brown rhyolite of FORBES ROBERTSON, 1949) and (4) reddish brown to bluish gray porphyritic rhyolite with pronounced flow structures.

Although observations have permitted determining the relative position of these rocks on several individual knobs, the sequence of the rocks over the entire area remains uncertain. One obtains the impression, however, that further mapping would definitely permit a correlation of the different flows and the establishment of sequences of extrusion or intrusion.

Mineralogically the rhyolites show a preponderance of orthoclase and quartz. Orthoclase is generally more abundant. Both minerals occur as scattered phenocrysts. Most of the orthoclase and quartz occurs in the groundmass. Oligoclase is present in small quantities in many of the rocks, and occurs as phenocrysts. Magnetite is also present in small quantities, and occurs as small grains in the groundmass. Small magnetite phenocrysts are sometimes present and may be observed in the hand specimen. Other minerals which have been observed to be present include epidote, piedmontite, leucoxene, calcite and sericite.

The texture of the rocks consists of scattered phenocrysts within a fine grained to cryptocrystalline groundmass. All the rocks contain some phenocrysts. The groundmass of many of the rocks appears to be the result of devitrification of former glasses. None of the rocks are glasses.

Structures present in many of the rocks include radiating and concentric spherulites of quartz and orthoclase, and layers and lenticular pods of quartz surrounded by layers of orthoclase. Some of the pods and layers constitute the primary flow layers which appear on the outcrops. In other cases, flowage is evidenced by constituents of the groundmass swirling around phenocrysts.

Most of the above textures and structures have been well described by HAWORTH (1895) and FRENCH (1956).

Black porphyritic rhyolite (Annapolis Felsite)- The black porphyritic rhyolite, or Annapolis felsite as called by FORBES ROBERTSON (1949), occurs on the exposed knobs directly east, north and southwest of the town of Annapolis. A small exposure occurs along Highway 49 south of the road within the town. Exposures also occur in the eastern portion of the area along Crane Pond Creek. The areas underlain by these rocks are colored in black on the geologic map.

These rocks have black groundmasses, pinkish gray feldspar phenocrysts and green patches of epidote. The epidote is scattered in places throughout the rock and generally occupies portions of the feldspar phenocrysts.

Strong flowage occurs in the exposures in Annapolis along Highway 49 just south of the road. The groundmass in the rock at this locality consists of thin, slightly irregular, discontinuous layers. These groundmass layers have undergone differential weathering.

The following is a microscopic description of the rock from the old May quarry which is on the hill in SE¼-SW¼ 14 31N-3E:

Mineral components include orthoclase, perthite, oligoclase, quartz, epidote and magnetite.

The rock consists of 84% groundmass (mostly orthoclase, quartz and magnetite), 10% feldspar phenocrysts and 6% quartz phenocrysts. Much of the groundmass is fine grained to cryptocrystalline. Orthoclase predominates throughout the groundmass.

The feldspar phenocrysts range from one to five mm. in length, and are euhedral to anhedral. They are broken in many places, corroded, and partially resorbed.

The quartz phenocrysts average one mm. in diameter. They are euhedral to subhedral and corroded.

Portions of the oligoclase phenocrysts have been altered to epidote. The epidote occurs as radiating fibers and granular aggregates. Epidote occurs also with small concentrations of magnetite. It also occurs in the groundmass and in the central portions of small globules of quartz. These globules of quartz range from 0.1 to 0.2 mm. in diameter and are round. These quartz globules form the centers of a very pecular structure (see figures 4 and 5). This structure consists of alternating, concentric, partly curved layers of quartz and orthoclase. The quartz layers are thicker than the orthoclase layers. Where many of the globules are closely spaced, the concentric layers from the different globules run together. The layers thus have a wavefront appearance with the convex side generally toward the cryptocrystalline groundmass. The largest structure of this type measures 7 mm. in diameter. This structure also occurs in the rhyolite about two and one-half miles to the east. The locality is just north of Highway F in C-E$\frac{1}{2}$-E$\frac{1}{2}$-SE$\frac{1}{4}$ 19 31N-4E. The structure is partially developed in the rocks on the knob in the east

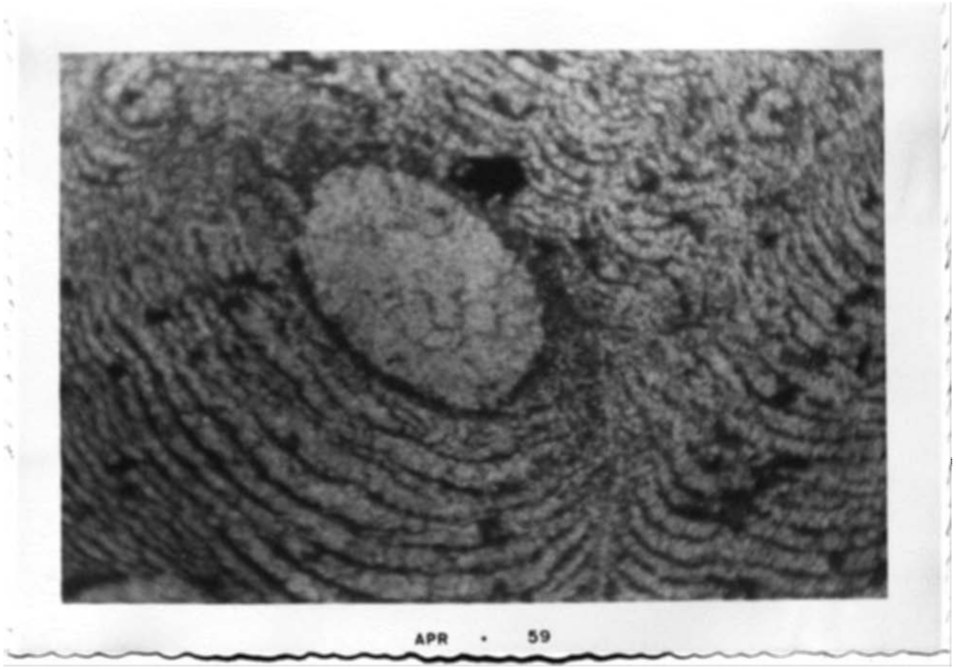


Figure 4. Alternating quartz (light bands) and orthoclase (dark) layers arranged concentrically away from quartz globules. Occurs in Annapolis Felsite. Enlargement 80X.

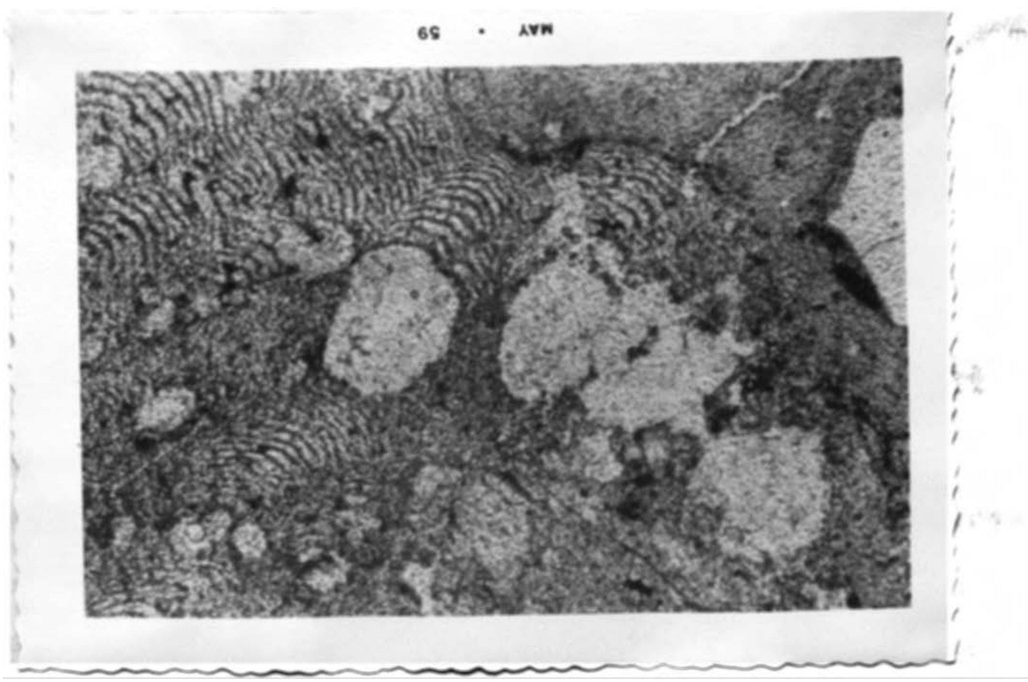


Figure 5. Same as Figure 4 but with several quartz globules. Very fine-grained to cryptocrystalline groundmass in upper right. Enlargement 60X.

portion of the area in NW$\frac{1}{4}$ 23 31N-4E.

The cryptocrystalline groundmass shows flow texture with long thin stringers of quartz oriented with the flow. The groundmass flows around phenocrysts.

Brittle, purplish black rhyolite- This variety of rhyolite occurs at only one locality. This is on the knob in the east portion of the area in S$\frac{1}{2}$-SE$\frac{1}{4}$ 23 31N-4E. The area underlain by this variety is colored in purple on the geologic map. A contact between these rocks and an underlying red felsite occurs on the hillside in C-N$\frac{1}{2}$-SW$\frac{1}{4}$ 23 31N-4E.

In the hand specimen, these rocks appear similar to the black Annapolis felsite, except that they lack the green epidote and contain only a few small phenocrysts. The groundmass is very similar in color to the Annapolis felsite. They have a glassy appearance, and splinter on breaking. One outcrop showed the rock to consist of felsite spherulites over one cm. in diameter.

The following is a microscopic description of the rock at the top of the hill just west of the road in C-S$\frac{1}{2}$-SE$\frac{1}{4}$ 23 31N-4E:

The rock contains a few small fragments and phenocrysts of quartz, feldspar and magnetite in a cryptocrystalline groundmass. The groundmass is mostly orthoclase. A few phenocrysts range from 0.5 to 1 mm. in diameter. Feldspars are mostly subhedral. Quartz and feldspar are corroded in places. All the feldspars show abundant alteration to clay minerals. Feldspar was originally perthite as evidenced by orthoclase which is still present.

Faint flow structure is present. The smaller fragments show a general orientation in a similar direction.

Reddish brown porphyritic rhyolite with large phenocrysts and aphanitic groundmass- (Chocolate brown rhyolite of F. ROBERTSON, 1949). These rocks are characterized by abundant feldspar and quartz phenocrysts. They have the coarsest groundmass of all the rhyolites. They occur in the knobs which form the large horseshoe in the north central portion of the area. The rocks in this horseshoe correspond to the chocolate brown rhyolite of FORBES ROBERTSON. They underlie the reddish brown porphyry with pronounced flow structure which forms the upper portion of Grassy Mountain. The exposed areas underlain by these rocks are colored in orange on the geologic map.

The following is a description of this rock as seen in a building stone quarry located on the ridge near the C-E$\frac{1}{2}$-NW$\frac{1}{4}$ 20 31N-4E: Here, the same porphyry is found as occurs in at least eight other quarries located along the ridge.

In the hand specimen the color is reddish brown with numerous white feldspar phenocrysts and a few quartz phenocrysts embedded in a dense groundmass. Feldspar phenocrysts range from 1 to 5 mm. in length and appear to be much more abundant than quartz phenocrysts. A few small grains and patches of magnetite and hematite are scattered throughout the specimen.

Microscopic examination shows the rock to consist of 77% groundmass and 23% phenocrysts; three quarters of the phenocrysts consist of feldspar and one quarter of quartz. The rock is holocrystalline and consists of about 52% orthoclase, 2% oligoclase, 41% quartz and 5% magnetite and hematite. The feldspar phenocrysts consist of orthoclase, perthite and oligoclase. Phenocrysts are 1 to 3 mm. in diameter with the feldspars generally larger than the quartz. They are subhedral to euhedral and occasionally corroded. Feldspars are broken in places and dragged with the flow. Numerous minute specks of magnetite occur throughout the groundmass. The groundmass consists of irregular, somewhat swirling patches of orthoclase and quartz. Under high power, some of the quartz in the groundmass appears cellular, with orthoclase in the cells. The rock from NW¼ 9 31N-4E shows a more pronounced development of this poikilitic or almost myrmekite-like texture. At this locality the groundmass consists of closely packed but nearly isolated equigranular accumulations of quartz, which under high power show the quartz to be well honeycombed with orthoclase (locking type 1c, figure 6).

Reddish brown to bluish gray porphyritic rhyolite with pronounced flowage- This variety of porphyritic rhyolite is characterized by a very fine grained to cryptocrystalline groundmass and usually well developed flow structure.

These rocks are distributed on Grassy Mountain and the knob to the east, along Crane Pond Creek, and on the knobs

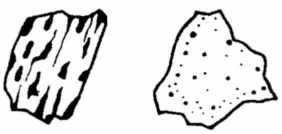
COMMON TYPES OF MINERAL LOCKING IMPORTANT IN ORE DRESSING

It is obvious that between most of these types there are gradational transitions. During grinding some of the more complicated types are converted into simpler ones (e.g. types 1b and 2a into type 1a). Economic liberation depends, of course, as much on particle size as it does on the type of locking. Therefore the remarks on ease of liberation are only valid for relatively large particles. Types of locking are of more use the more a sample is split in size fractions.–

Type 1a. Simple locking; rectilinear or gently curved boundaries. Most common type of locking. Liberation fairly easy.

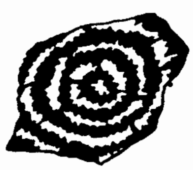
Type 1b. Mottled, spotty, but simple locking. Common type of locking. Liberation fairly easy.

Type 1c. Graphic or myrmekitic locking. Example: Sphalerite and galena, etc. Complete liberation usually impossible.

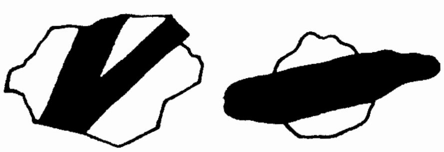


Type 1d. Disseminated, emulsion like, or drop-like locking. Example: chalcopyrite in sphalerite. Complete liberation difficult or impossible.

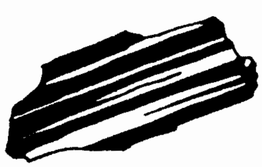
Type 2a. Coated, mantled, enveloped, covered, rim-like, ring-like, or shell-like locking; "atoll"-texture. Example: Chalcocite or covellite mantling pyrite or sphalerite. Complete liberation fairly difficult.



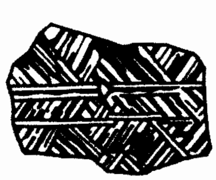
Type 2b. Concentric or spherulitic locking. Example: Uraninite with galena, bismuthite, chalcopyrite, bornite. Liberation very difficult.



Type 3a. Vein-like, stringer-like, sandwich-type locking. Fairly common type. Complete liberation usually fairly easy.



Type 3b. Lamellae, or polysynthetic locking. Not very common type. Ease of liberation variable.



Type 3c. Network-or boxwork-locking. Example: Hematite-ilmenite-magnetite; chalcopyrite-pyrite; anglesite and covellite in galena; etc. Liberation difficult or impossible.

G.C. Amstutz 1954.

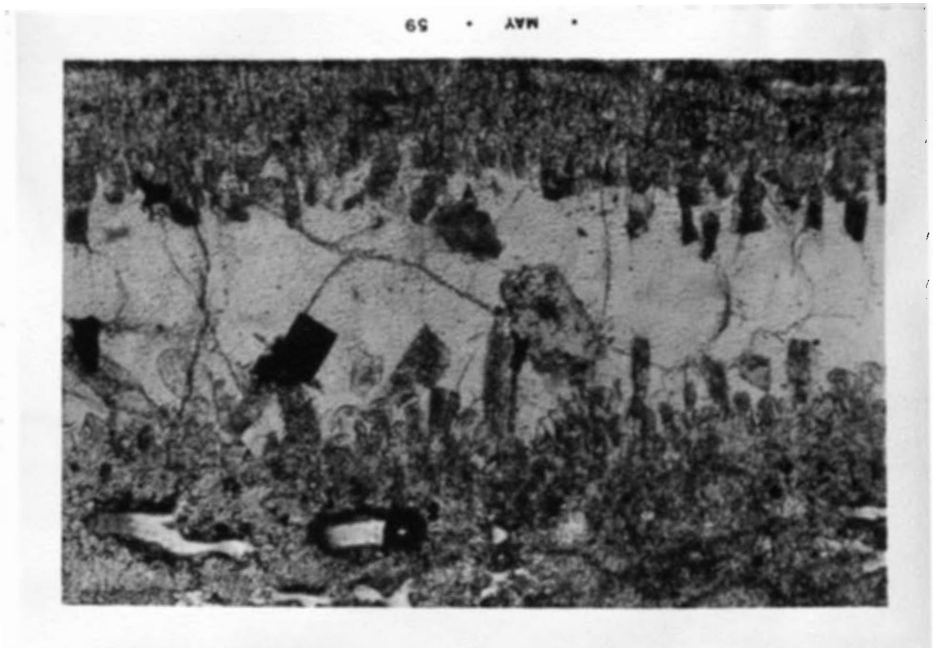


Figure 7. Micropegmatitic layers of quartz surrounded by orthoclase in the porphyritic rhyolite near the top of Grassy Mountain in C-NE$\frac{1}{4}$-SE$\frac{1}{4}$ 12 31N-3E. Note euhedral orthoclase crystals projecting into, and enclosed in quartz. Enlargement 60X.

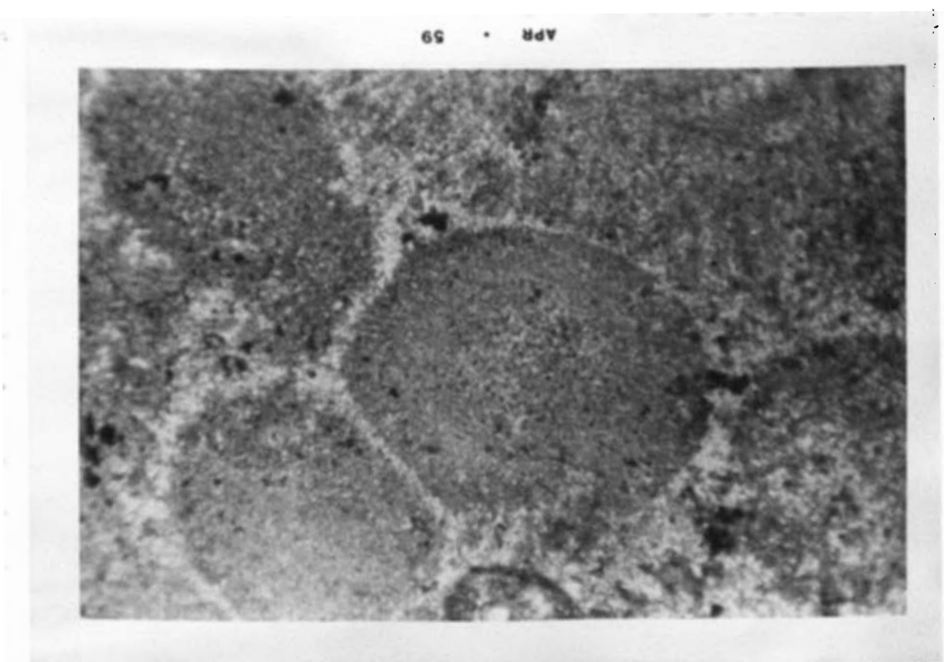


Figure 8. Spherulites of quartz and orthoclase in the porphyritic rhyolite at C-W$\frac{1}{2}$-W$\frac{1}{2}$-SW$\frac{1}{4}$ 9 31N-4E. The light network consists mainly of quartz, whereas the dark globules contain more orthoclase. Enlargement 80X.

south of Annapolis. The rocks on the knobs south of Annapolis are named Red Rhyolite by FORBES ROBERTSON.

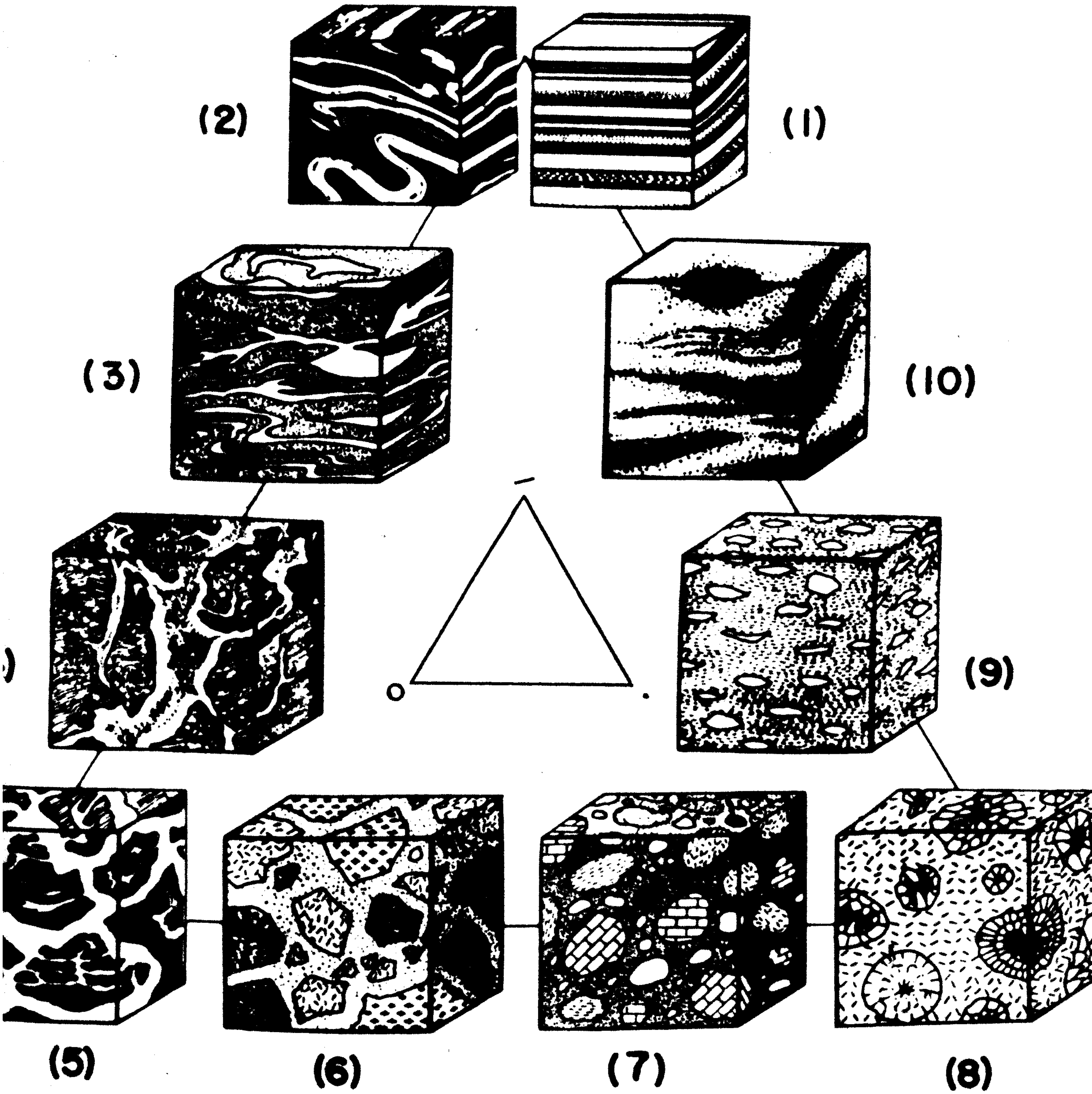
The following is a description of the rock from Grassy Mountain just southeast of the summit:

The outcrop is about 60' long and 25' wide and trends N50E along side the hill. Weathered and fractured surfaces are bluish gray with very light reddish orange bands (flow layers), with large, light reddish orange patches in the plane of layers (this is apparently fine grained orthoclase). Quartz appears to predominate in the layers. These "flow layers" are one-eighth inch to one inch thick. The average thickness is about one-eighth of an inch. This shape is most similar to the NIGGLI rock texture No. 10 (see figure 9), with transitions to type 1 and 9. These layers strike N-S and dip 16E.

Microscopic examination shows the rock to contain numerous layers of quartz surrounded by orthoclase. (See figure 7). Small euhedral orthoclase crystals project into the quartz. Some occur as isolated crystals completely enclosed in quartz. The layers are of all sizes and range up to several mm. in thickness. The groundmass is equigranular and very fine grained with flow the texture well developed throughout its entirety. The groundmass shows patchy extinction when viewed under crossed nicols.

A few quartz and feldspar phenocrysts are distributed in the groundmass. Most of the phenocrysts are orthoclase and perthite. Quartz is subhedral to angedral and corroded.

THE NIGGLI CLASSIFICATION OF ROCK TEXTURES



<u>Purely geometric nomenclature of rock textures</u>
free of genetic interpretations, for chorismites or chorismatic, polyschematic rocks or mineral deposits (= rocks which consist of two or more textural units).

1 and 2 = Stromatites
3 and 4 = Phlebites
5 and 6 = Merismites

7, 8, 9 = Ophthalmites
(8 = Miarolithite)
10 = Nebulite

Legend for Figure 9 (purely geometric terms, free of genetic connotations)

All these ten basic types are together called chorismites or chorismatic, polyschematic rocks or mineral deposits (i.e., consisting of two or more textural elements).

1 and 2 = stromatites:	layered rocks, flat or folded, but always with essentially parallel texture.
3 and 4 = phlebites:	one of the two or more textural elements begins to assume cross-cutting and irregular shape.
5 and 6 = merismites:	one of the two or more elements forms a coherent, polygonal or cellular network.
7, 8, 9 = ophthalmites:	one element forms eyes (Greek = ophthalmos) in a matrix (type 8 was originally separated and called miarolithite).
10 = nebulite:	one textural element occurs as cloudy, nebulous lenses or streaks in the other.

The ten textural types were arranged for teaching purposes in a triangular array by G.C.AMSTUTZ. The corners of the triangle correspond to the three basic geometric forms: the point, the line, and the circle.

Feldspars are, for the most part, euhedral to subhedral and also corroded. Piedmontite is distributed as grains in the feldspar phenocrysts and in the groundmass. Some of the feldspar shows a very faint pinkish hue. This may be due to the presence of very fine particles of piedmontite or a fine dissemination of hematite. Magnetite occurs as very small grains and is evenly distributed throughout the groundmass.

The rhyolite at the top of the knob just south of Annapolis in C-S½ 22 31N-3E consists of quartz and very large feldspar phenocrysts embedded in patchy areas of cryptocrystalline groundmass. Radiating spherulites of quartz and euhedral orthoclase occur between the patchy cryptocrystalline groundmass areas (see figures 10 and 11).

The rhyolite on the knobs in the southwest portion of the thesis area in NE¼-SE¼ 4 30N-3E consists of quartz and feldspar phenocrysts embedded in a fine grained reddish brown groundmass. The groundmass here consists of closely packed orthoclase crystals with thin lamellae of "trapped" quartz as "matrix" between the crystals (see figure 13). Magnetite is relatively abundant (approximately 5%). Leucoxene and epidote are also present.

The groundmass of the rhyolite in NW¼-SW¼ 9 31N-4E is fine grained to cryptocrystalline and consists of spherulites of quartz and orthoclase. Spherulites average 0.5 mm. in diameter (see figure 8).

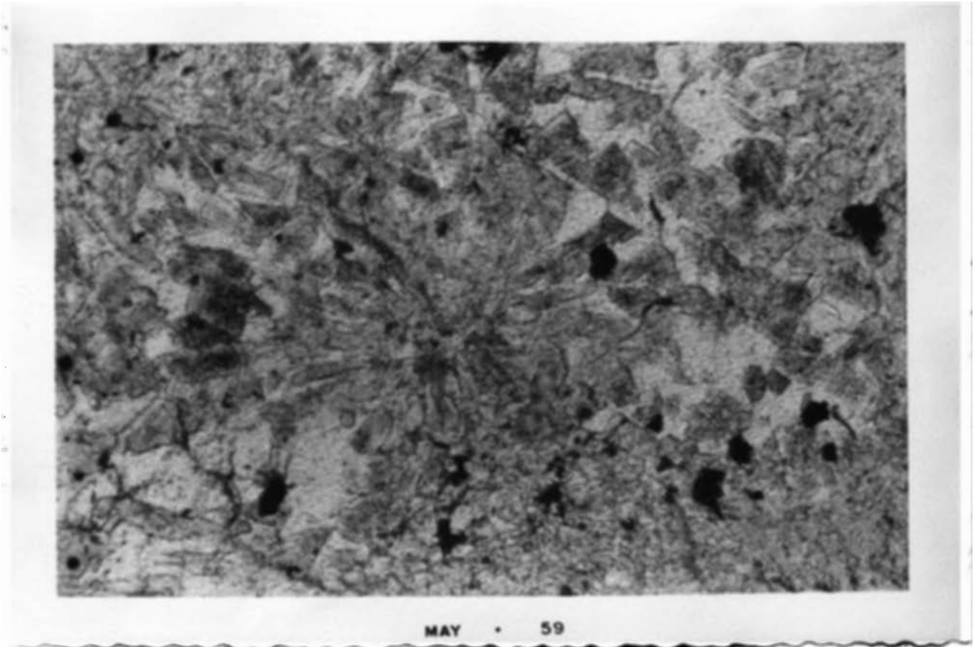


Figure 10. Radiating spherulites of quartz and euhedral orthoclase in the porphyritic rhyolite at the top of the knob just south of Annapolis in C-S½ 22 31N-3E. The light gray is quartz; the dark gray is orthoclase. Enlargement 60X.

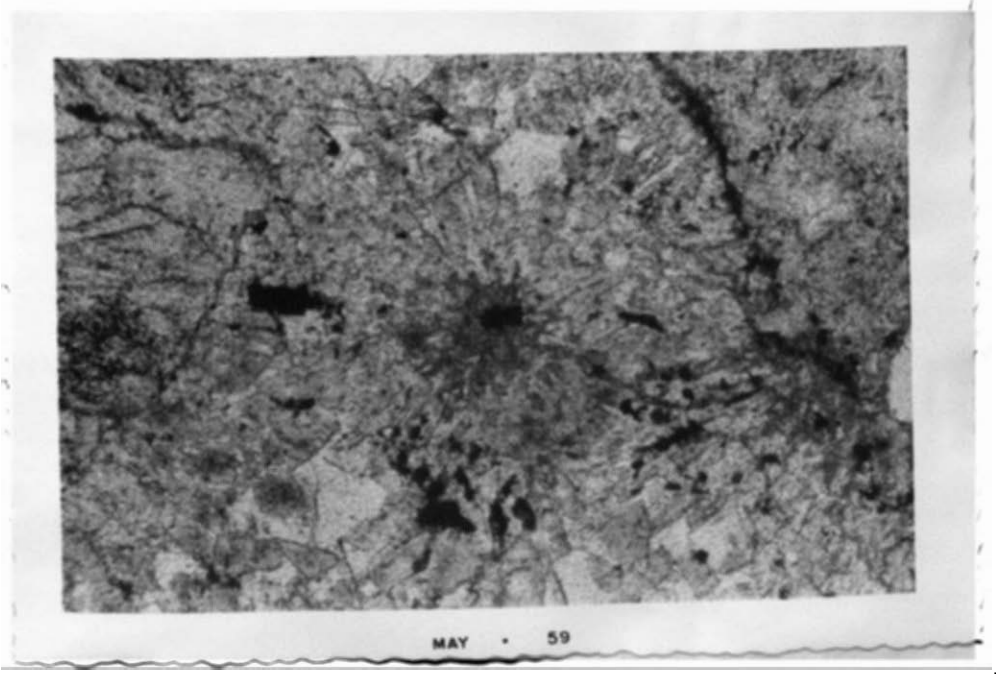


Figure 11. Radiating spherulites of quartz and orthoclase from same locality as described in Figure 10. Enlargement 60X.

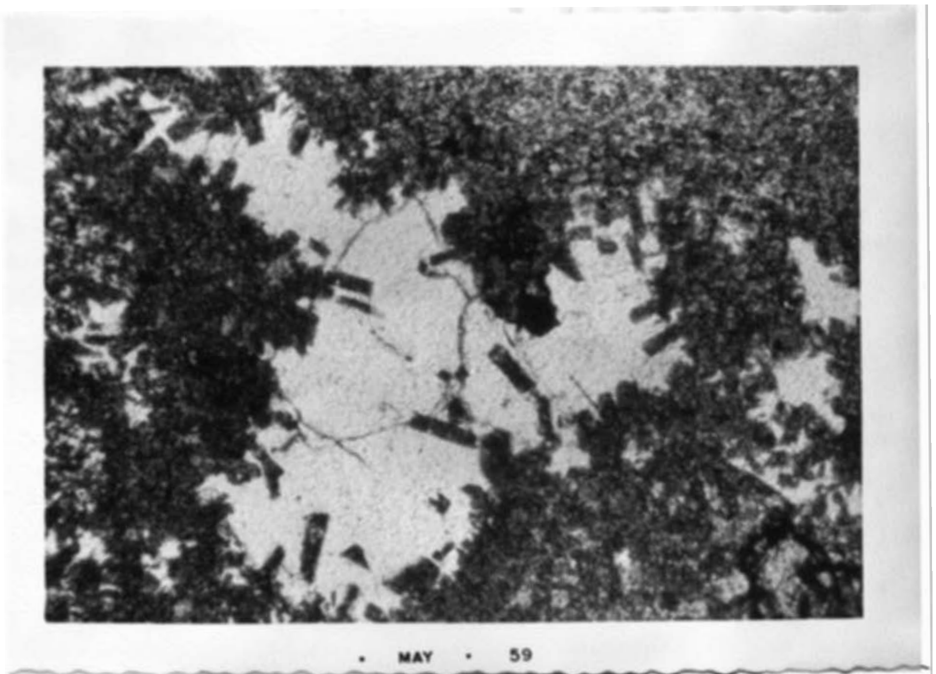


Figure 12. Small crystals of orthoclase projecting into and enclosed in quartz (micropegmatitic). Section from outcrop between sections 10 and 11 31N-4E. Enlargement 60X.

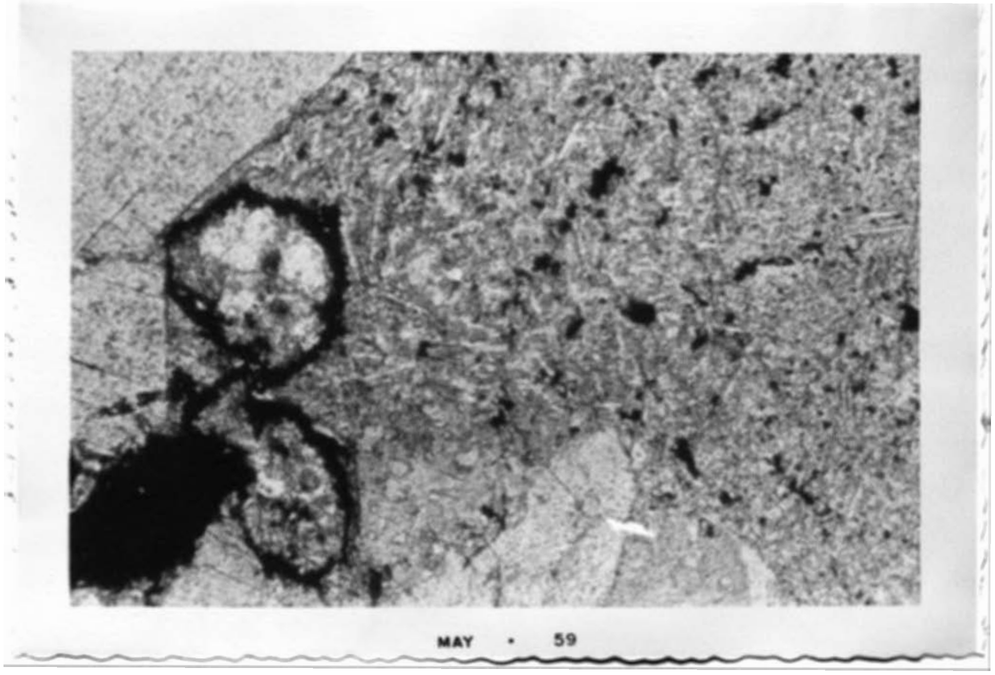


Figure 13. Quartz(?) needles (light gray) oriented with flow in the groundmass in the porphyritic rhyolite at the top of the knob in the southwest portion of the thesis area in NE$\frac{1}{4}$-SE$\frac{1}{4}$ 4 30N-3E. Enlargement 60X.

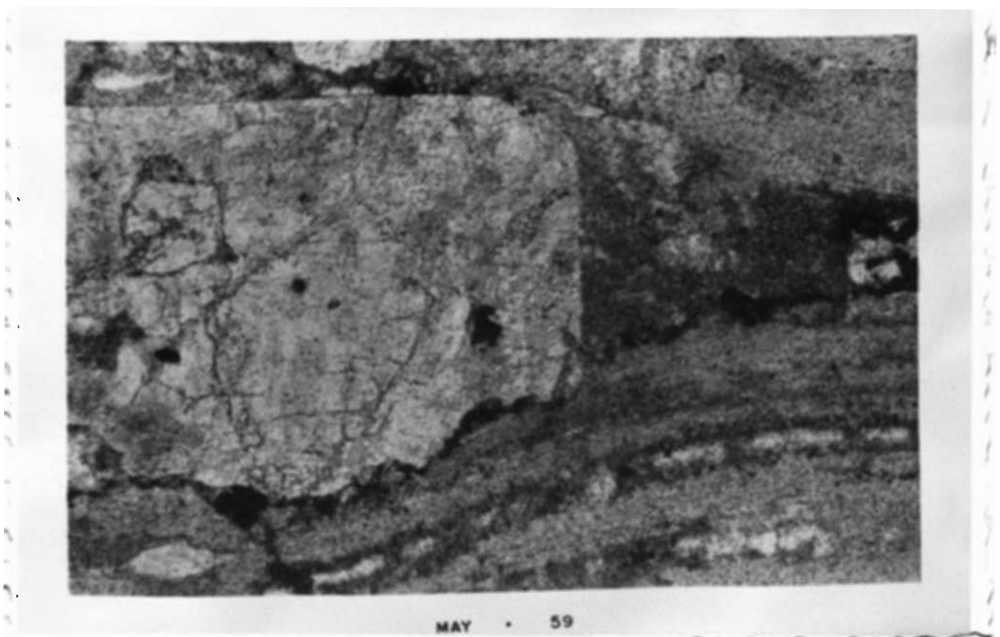


Figure 14. Flowage around a feldspar phenocryst in the porphyritic rhyolite at C-N$\frac{1}{2}$-N$\frac{1}{2}$-NW$\frac{1}{4}$ 23 31N-4E. Enlargement 60X.

b. Diabase

Diabase outcrops occur on the west side of Highway C about 50' from the road in the igneous rock area in NE$\frac{1}{4}$ 24 31N-3E.

The area underlain by these diabase outcrops is 30' long and 5' wide and trends N32W. One end of the area is 40' south of the stream; the other end is just south of the point where the water cascades over the largest of the small shut-ins.

The surrounding rocks are rhyolite. The flow layers strike N30E and dip 22 SE. The rhyolites appear as massive sheets with jointing nearly parallel to the flow layers. The contacts between the diabase and rhyolite are not exposed, and the outcrops do not permit either a determination of a strike and/or dip of this basic rock. It is thus not sure whether we are dealing with a dike or a sill or some sort of irregular body.

In the hand specimen the rock is greenish black with a faint dull shade of green. The texture is diabasic. Large phenocrysts are sparsely distributed in the fine grained diabasic groundmass. Phenocrysts range up to 1 cm. long.

Microscopic examination shows the rock to contain 50% andesine, 37% hornblende and 7% magnetite. The determination of the andesine was made by the symmetric maximum extinction angle method and the refraction index. The phenocrysts consist of sericite and a zeolite(?). The groundmass grains average about 0.5mm. in length. The feldspar grains are altered in places to a flaky silicate mineral (clay minerals or sericite).

Rhyolite occurring close to the diabase carries abundant green epidote. Examination under the microscope shows the rock to be shot through with small fractures. Fractures are filled with calcite, quartz and epidote. Perthite and orthoclase phenocrysts close to the contact are almost entirely altered to quartz and sheet silicate minerals.

2. Paleozoic Sedimentary Rocks

The sedimentary rocks occurring in outcrops in the thesis area include dolomites, calcareous dolomites, dolomites with porphyry fragments and arkoses. Lamotte sandstone occurs on the dumps at the old Annapolis lead mine. (See also Lead, under ECONOMIC RAW MATERIALS.) The dolomites and calcareous dolomites constitute, by far, the bulk of the sedimentary rocks. Dolomites with porphyry fragments occur in the carbonates along the margins of exposed igneous knobs. Arkose was observed in two localities.

Differences in lithology have been observed whereby all the carbonate rocks may be divided into four lithologic units described below. The differences are based on bedding thicknesses, grain-size, size and amount of vugs, insoluble matter such as silica and shale, crossbedding, appearance of weathered surfaces, color and shades and other visible features which may be observed on the outcrop.

Unit 1 consists of massive beds of coarse-grained, vuggy, glauconitic calcareous dolomite with green shale in places. The rocks of this unit have a "Bonneterre" appearance (see DAKE, 1930, p. 105). Unit 2 consists of thin to massive beds of fine to medium-grained calcareous dolomite. Wavy flaggy beds with large elliptical calcite vugs characterize this unit. Unit 3 consists of massive beds of porous, siliceous, cross-bedded calcareous dolomite. These beds are believed to be equivalent to the massive Derby-Doerun beds which occur along Highway 32 near West Elvins. Unit 4 consists of very massive beds of medium to fine grained somewhat vuggy dolomite. The rocks of this unit contain quartz druse with large masses of cellular silica and druse occurring in the dolomite high in the section. These beds have a Potosi appearance in places.

Unit 1 underlies Units 2, 3, and 4. In various places, however, it overlies Unit 2 or is believed to grade laterally into Units 2 and 3. Unit 3 (massive beds of the Derby-Doerun formation) overlies Unit 2 (see figure 15). The contact that is most extensively displayed throughout the area is between Unit 1 and Unit 4.

The age of these rocks is apparently Upper Cambrian as indicated by the fossil gastropod Cloudia buttsi (?) which occurs in Unit 4. This is the only fossil that was found in the area (see figure 31). (See Chapter III 2d, notes on Paleontology).

The relations of the sedimentary rocks with known Missouri formations are based on the following facts, assumptions and arguments:

Massive beds of dolomite along Big Creek possess such marked similarities with the massive Derby-Doerun beds near the type section (along Highway 32 near West Elvins) that they have warranted mapping as a separate unit. The Derby-Doerun beds overlie beds of Unit 2 and are believed to form part of Unit 4.

Derby-Doerun characteristics are present in Unit 1 beds in the west fork of the Mine Hollow. These beds directly

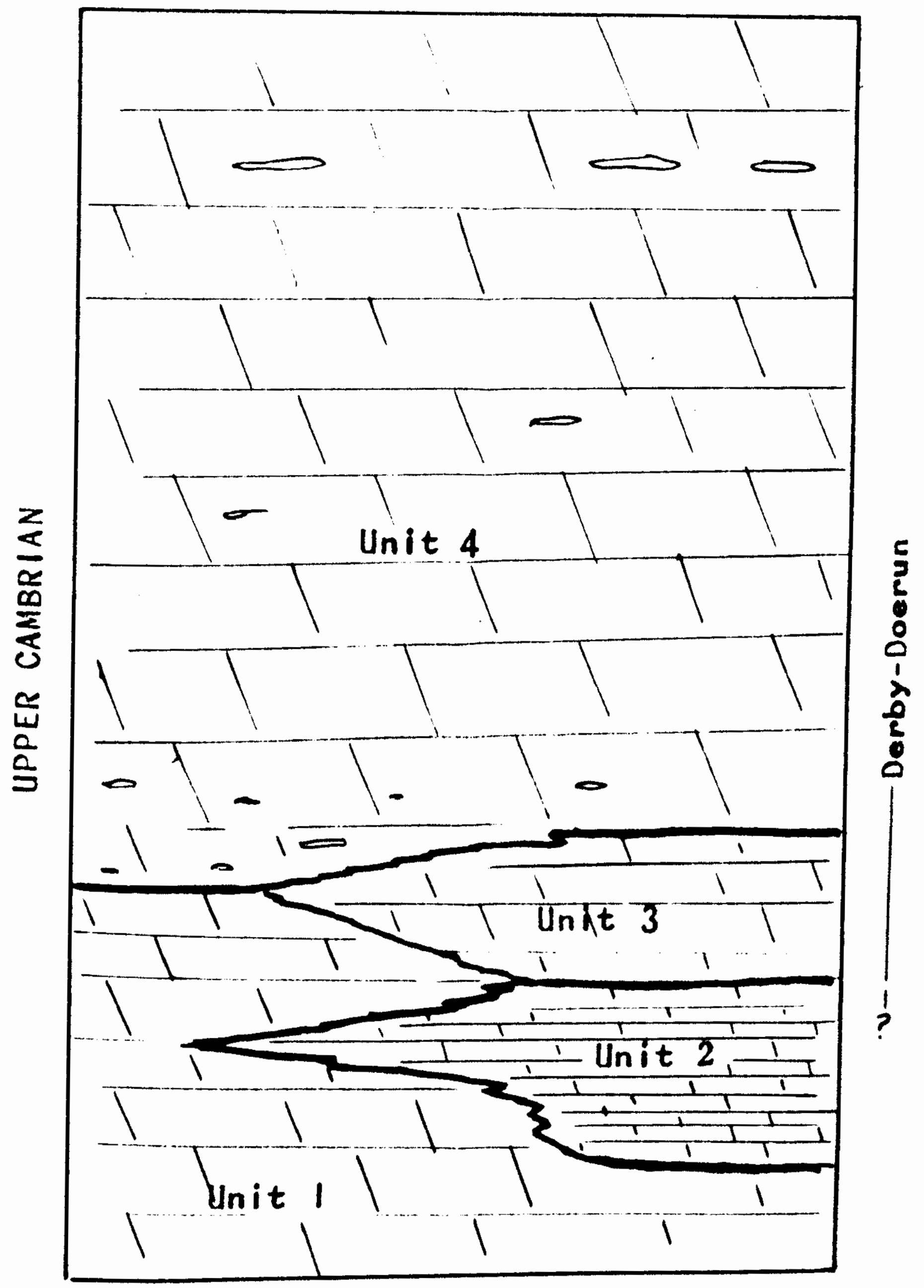


Figure 15. Columnar section for sedimentary rocks in thesis area.

overlie beds that are very similar to flaggy beds (Unit 2) along Big Creek. The flaggy beds along Big Creek underlie typical massive Derby-Doerun beds.

The Unit 1-Unit 4 contact has been observed in several localities in both the west and east portions of the thesis area (i.e., along Big Creek and Crane Pond Creek). This contact divides two different and persistent lithologies. It is believed to represent DAKE's (1930, p. 105) Bonneterre-Potosi contact or unconformity.

In the west portion of the area (along Big Creek) the rocks on both sides of this contact have been placed in the Derby-Doerun formation by results of studies on the lithology and insoluble residues of samples from 15 measured sections along Big Creek valley.

Since the same Units (Unit 1 and Unit 4) occur on both sides of the same contact in the east portion of the area (along Crane Pond Creek), it should follow that these rocks must be Derby-Doerun also. However, according to results from the insoluble residues from three sampled localities in the northeast portion of the area, the Unit 1 rocks have been placed in the middle Bonneterre (?). The results from these samples are not in agreement with those along Big Creek. The results from the three sampled localities in the northeast portion of the area could be assumed to be incorrect in order to keep the relations consistent. The argument that the samples from these areas should agree with those along Big Creek is given under Unit 1 "Relations with known formations" (Chapter III 2a).

Conversely the lower part of the column could very easily be represented in the northeast portion of the area, since passage from the Derby-Doerun into the Bonneterre would constitute probably no more than an intervening 90' thickness of Davis. Therefore arguments in favor of this portion of the area belonging to the Bonneterre formation are also given under "Relations with known formations" under Unit 1 (Chapter III 2a).

a. Unit 1

Name and areal distribution:

The name Unit 1 is used here to designate the rocks which directly underlie Unit 2, Unit 4 the massive beds of the Derby-Doerun formation. They have also been observed to overlie Unit 2. They are believed to grade laterally into Unit 2 and the Derby-Doerun, which is Unit 3.

The rocks of Unit 1 occur as massive beds of coarse-grained, vuggy, glauconitic, slightly calcareous dolomite. Everywhere they show a strong similarity in lithology. Beds belonging to this Unit have a "typical Bonneterre" appearance.

These beds apparently form part of the Davis and part of the Derby-Doerun formations. They may belong to the Bonneterre formation in the northeast portion of the area. Because the location of formational contacts is uncertain, sections showing Unit 1 type of lithology were mapped as a lithologic unit without assigning formational names to them.

Beds belonging to Unit 1 crop out most abundantly along Big Creek, Crane Pond Creek, Richland Creek and Funks Branch. They are colored in blue on the geologic map.

Lithology and thickness:

The beds of Unit 1 consist of coarse-grained, vuggy, glaucenitic, slightly calcareous dolomite with green shale in places. Typical exposures occur along the roadside on Highway 49 (see figure 16) in C-NE¼ 23 31N-3E. The section is 4' thick where it crops out directly along the road. The beds strike N10E and dip 10E. The dip is off of the knob with exposed igneous rocks about ¼ mile to the northwest.

A 67' cliff forming a sequence of massive beds directly underlying beds of Unit 4 occurs on the high bluff on the east side of Crane Pond Creek about 500' north of the Creek ford on Highway F in C-SE¼-SW¼ 26 31N-4E. The massive beds strike N80W and dip 10 to 15° SW.

The following section, from top to bottom occurs at this locality. This section shall be referred to as Unit 1, Section 1.

Unit 1 - Section 1

Top	M.	Cm.	Ft.	In.	
(17)	1	22	4		Bed of very coarse-grained, light gray, highly pitted, calcareous dolomite with numerous small vugs lined with buff colored calcite crystals.
(16)		46	1	6	Hard, slightly vuggy coarse-grained dolomite.

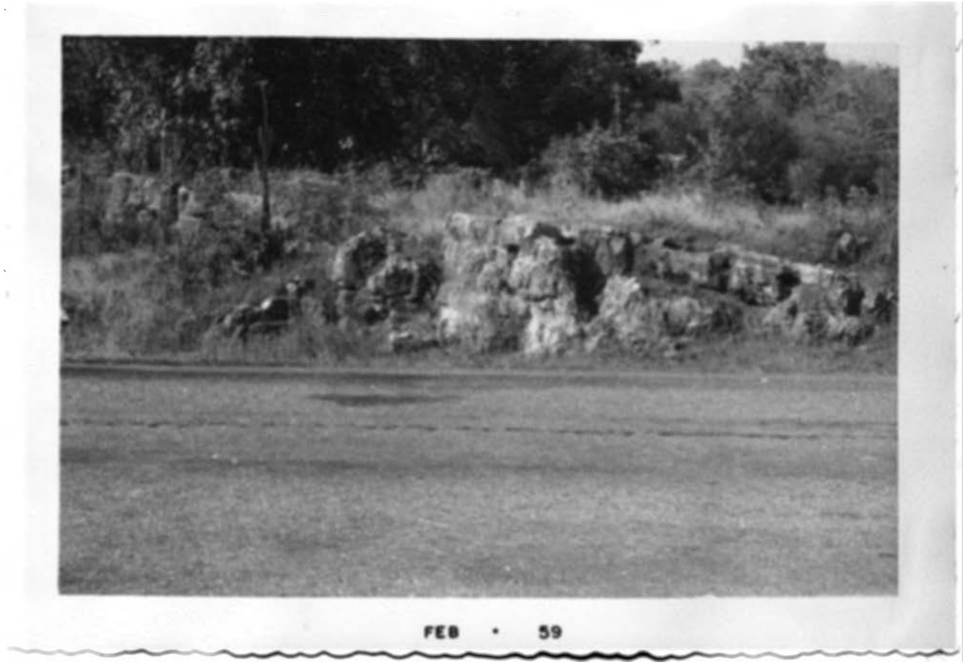


Figure 16. Typical Unit 1 exposures along north side of Highway 49 just east of Annapolis in C-NE¼ 23 31N-3E.

Figure 17. Unit 1 outcrops in the west fork of the Mine Hollow in C-SE¼ 14 31N-3E. They show Derby-Doerun characteristics. These beds are laterally equivalent to the beds shown in Figure 16.

	M.	Cm.	Ft.	In.	
(15)		46	1	6	Coarse-grained, friable, medium gray, glauconitic, slightly calcareous dolomite.
(14)		30½	1		Medium to coarse-grained, buff colored, highly calcareous dolomite.
(13)		61	2		Ledge forming Bed with rock similar to (16).
(12)			2	6	Ledge forming bed with rock similar to (16) with some glauconite.
(11)		76	2		Similar to (16).
(10)		30½	1		Massive bed similar to (16) with numerous irregular 1" bumps projecting on weathered surface.
(9)		46	1	6	Highly glauconitic, calcareous dolomite, dark gray to buff colored patches (1½" in diameter) of medium gray, calcareous dolomite surrounded in places by 1/8" rims of light coarse-grained dolomite.
(8)	2	74	9		Calcareous dolomite; coarse-grained, glauconitic and vuggy toward top.
(7)		61	2		Brownish gray dolomite with large irregular ½" to 1½" vugs lined with buff colored calcite crystals; weathered surface with 1" to 3" pits.
(6)	1	22	4		Coarse-grained, medium gray, glauconitic, calcareous dolomite with ¼" to 3/4" vugs partially filled with 1/8" to ¼" calcite crystals.

	M.	Cm.	Ft.	In.	
(5)	1	83	6		Medium gray dolomite similar to (3) and (16).
(4)	1	83	6		Bed with rock similar to (3); 2' solution cavity within local V-shaped accumulation of rounded dolomite fragments cemented with calcite (cavity due to solution of calcite).
(3)	3	66	12		Bed medium to coarse-grained of very light tanish gray dolomite with a few very small buff colored vugs thinly lined with calcite crystals; weathered surface dark gray to black in color and smooth except for ¼" to ½" pits elongated parallel to bedding.
(2)	2	74	9		Coarse-grained, calcite cemented, rounded, Calcareous dolomite masses ranging up to 1' in diameter with masses showing spheroidal weathering in places; solution cavity about 40' long, 8' high and 10' into bed occurs in this zone; other solution cavities up to 2' in diameter also present. Large masses of crystalline calcite between (1) and (2).
(1)		61	2		Medium to coarse-grained brownish gray dolomite; weathered surface smooth with some holes.
Bottom					

The above section is the thickest complete section that was observed in the area.

The most conspicuous features of this section include the following:

1. Massive beds, coarse-grained.
2. Large buff colored vugs and pitted weathered surfaces.
3. Calcareous dolomite with calcite lining the vugs.
4. Abundant glauconite in places.
5. Larger masses of calcite in the lower part of the section cementing rounded dolomite fragments.

Most of these features characterize the beds mapped throughout the thesis area as Unit 1. Dolomite masses which have been cemented by calcite occur in one other locality in the area. This is on the north side of Richland Creek along the edge of the Creek in the C-E $\frac{1}{2}$- SW$\frac{1}{4}$-SW$\frac{1}{4}$ 31N-3E. The calcite cemented dolomite masses range from 1' to 2$\frac{1}{2}$' in diameter.

A very thick section of Unit 1 apparently occurs south of Stony Mountain along Big Creek. Outcrops with rocks of this section occur on the north side of the hollow in the C - E$\frac{1}{2}$ 25 31N-3E, at 690' elevation (altimeter), and at 650' on the top of the hill on the south side of the hollow. Unit 1 outcrops also occur in places down along the hollow and along Big Creek. The maximum thickness of this section should be greater than 90'.

Porphyry fragments in dolomite occur along the east side of Crane Pond Creek in section 26. Arkose grading into dolomite with porphyry fragments occurs in the C - S$\frac{1}{2}$ 26 31N-4E.

Arkose masses attached to dolomite (not float) occur in C - E½-SE¼ 22 31N-3E. The arkose consists of porphyry fragments and sand. They have a brown color. The masses follow a linear trend for about 16 feet with bearing N25W.

These arkose masses are believed to be remnants of an old stream channel. A present day creek close by follows a similar course down the hill to the north.

Relations with overlying and underlying rocks:

Unit 1 beds underlie all three of the upper Units, namely Unit 2, Unit 3, (typical massive beds of the Derby-Doerun formation) and the massive beds of Unit 4. They also overlie Unit 2 and are believed to grade laterally into Unit 2 and the Derby-Doerun. For evidence indicating these lateral gradations see the next section entitled "Relations with known formations". Unit 1 underlies beds of Unit 2 at Dead Man's Curve below Highway 49 in C-S½-NE¼-SE¼ 3 31N-3E. Unit 1 overlies beds of Unit 2 in the west fork of the Mine Hollow in C-SE¼-SE¼ 14 31N-3E. Two massive "folded" beds of Unit 1 aggregating 18' in thickness are overlain by massive bedded Derby-Doerun on the bluff on the south side of Big Creek in C-E½-SW¼-NE¼ 22 31N-3E.

The contacts between these units have been drawn on the basis of distinct differences in lithology and bed thickness. The beds along these contacts all show conformable relations.

Unit 1 underlies Unit 4 in several places throughout the thesis area. The contact occurs at the following localities in the western portion of the area: (1) C-SE$\frac{1}{4}$ 15 31N-3E at the bottom of the hill, (2) C-N$\frac{1}{2}$-N$\frac{1}{2}$-NW$\frac{1}{4}$ 25 31N-3E at the top of the hill on the road leading to Warneke's house, and (3) C-NW$\frac{1}{4}$-NW$\frac{1}{4}$-SE$\frac{1}{4}$ 23 31N-3E along the northwest side of the hillside. (See also "Relations with known formations" for locations of Unit 1-Unit 4 contact in the eastern portion of the area).

Usually the contact is marked by a thin zone of green shaly material.

The very massive beds of Unit 4 are often nearly vertically jointed and contain varying amounts of quartz druse.

The contact is well shown in the last named locality (i.e. C-NW$\frac{1}{4}$-NW$\frac{1}{4}$-SE$\frac{1}{4}$ 23 31N-3E along Big Creek). About 29' of Unit 1 underlies (only 4$\frac{1}{2}$' directly) a wavy contact with an amplitude of 3" to 6". Green shale occurs along the contact. One and one-half to three and one-half feet above this wavy contact occurs another slightly wavy contact. Coarse-grained dolomite similar to the lower beds occurs between the two contacts. Eighteen feet of beds belonging to Unit 4 occurs between the second contact and the top of the hill. These beds are nearly vertically jointed, contain quartz druse and are similar to the Unit 4 beds occurring throughout the thesis area.

A similar contact between the two Units is very well shown along Crane Pond Creek in the eastern portion of the area at C-SW$\frac{1}{4}$-NW$\frac{1}{4}$-NW$\frac{1}{4}$ 26 31N-4E. The beds here occur directly along the west side of the Creek and dip 6NW.

The Unit 1-Unit 4 contact is believed to represent the Bonneterre-Potosi unconformity as postulated by DAKE (1930, p, 104-106).

Well logs and samples taken for insoluble residues have apparently disproven that such is actually the case. (See "Relations with known formations" which follows).

Relations with known formations:

In 1930, DAKE (1930, p. 105) stated that "At numerous points along the new State Highway (49) both north and south of Annapolis, the contact of Potosi on Bonneterre is well exposed."

It is presumed that the beds in Unit 1 are those which DAKE considered to belong to the Bonneterre formation. He reports an actual unconformity between what he considers Bonneterre and Potosi, but does not give however a specific location and description of it inside the thesis area. What he considers an unconformity is thus only based on analogies to adjacent areas and lithologic changes. Yet, as shown on figure 15 Unit 3 grades locally into Unit 4 which speaks against an unconformity.

Since DAKE's publication, many drill holes have been put down throughout the Annapolis area. Much of this drilling was done recently by the St. Joseph Lead Co. Mr. R. E. WAGNER, Geologist for the St. Joseph Lead Co., states that coarse grained beds similar to those in Unit 1 occur in places in the Bonneterre, Davis, Derby-Doerun and Potosi formations throughout that St. Francis mountain area. The term, "White Rock" is used for this type of lithology.

In 1947, KIDWELL mapped the beds of Unit 1 in the vicinity of Annapolis as belonging to the Derby-Doerun formation. This mapping was aided by results of the insoluble residues from samples taken from measured sections at the different points on the surface along Big Creek valley.

A study of well logs at the Missouri Geological Survey indicates that sedimentary thicknesses up to 500' and 600' occur in places where Unit 1 crops out at the surface. The well logs, show that the surface outcrops belong to the Derby-Doerun formation.

Beds of Unit 1 belong to the Derby-Doerun formation as shown by insoluble residue studies. This type of lithology is non-existant in the type section. The possibility of these belonging to the Bonneterre formation is eliminated by the fact that well logs show the Davis formation to occur in most of the area beneath the surface.

From the relationships observed in the field some statements can be made concerning the relations of these rocks with the known formations.

At one locality (C-E½-SW¼-NE¼ 22 31N-3E) (see also "Relations to overlying and underlying rocks of the Derby-Doerun) two massive "folded" beds (see below) of Unit 1 were observed to directly underlie very typical massive beds of Derby-Doerun along Big Creek. This would suggest that the underlying beds also belong to the Derby-Doerun or to the Davis formations.

The coarse-grained beds in the western fork of the Mine Hollow (these beds are also similar to those in the creek along the north side of Highway F in NW¼ 30 31N-4E), which overlie beds of Unit 2 (see below) have typical massive Derby-Doerun characteristics (see figure 17). One-half mile to the south, apparently the same beds dip off of the same knob and crop out along Highway 49 (see figure 16). These beds are very similar to those along high bluff on the upper portion of Richland Creek. These beds along Richland Creek are believed to grade laterally into Derby-Doerun to the southeast (see below). The beds on Richland Creek are similar to those along Crane Pond Creek at Highway F. It appears that these scattered outcrops all belong to the same formation (i.e., they all may be part of the Derby-Doerun formation).

The beds of Unit 2 (above) in the western fork of the Mine Hollow underlying the coarse-grained beds with Derby-Doerun characteristics, are very similar to the beds in Unit 2, Section 1, underlying Derby-Doerun Section 1 (insoluble residue studies showed the beds of Unit 2 Section 1 to be Derby-Doerun). Insoluble residue studies showed the beds in the Mine Hollow (Unit 2) to be either Bonneterre or Davis. Apparently they belong to the Derby-Doerun formation since insoluble residue studies placed the same set of beds below Derby-Doerun Section 1, in the Derby-Doerun formation. The relationship (see above) (Unit 1 and Derby-Doerun) along Richland Creek is believed to be caused by an abrupt lateral change in lithology. Eight feet of massive beds of Unit 1 occur on the north side of the hollow (at 775' elevation) in C-NW$\frac{1}{4}$-NW$\frac{1}{4}$-SE$\frac{1}{4}$ 9 31N-3E at the tree line on the hill. An entirely different, somewhat Derby-Doerun type of lithology occurs just to the south on the other side of the small hill.

Gradation in lithology between Unit 1 and Unit 2 is believed to occur. Unit 2 is underlain by about 15' of thick coarse-grained beds on the cliff below Dead Man's Curve at C-S$\frac{1}{2}$-NE$\frac{1}{4}$-SE$\frac{1}{4}$ 3 31N-3E. Gradation in lithology is believed to be the case here since the coarse-grained beds could not be located in the section to the south on either side of Big Creek, where the beds increase in elevation as the igneous knob to the south is approached. The relationship between these coarse-grained beds and the overlying Derby-Doerun at Derby-Doerun Section II, a short distance to the south, is similar to the above-mentioned relationship which exists at one point along Big Creek where two massive "folded" beds (see above) underlie typical Derby-Doerun. The coarse-grained beds from both localities are very similar. These beds probably occur at the same stratigraphic position as those in Unit 2, Section I underlying Derby-Doerun - Section I. If the beds in Unit 2 Section I are Davis, then the possibility exists that these coarse-grained beds are Davis also.

As has already been stated under "Relations to overlying and underlying rocks", the contact between Unit 1 and Unit 4 has been observed in several different areas.

The contact between Unit 1 and Unit 4 in the eastern portion of the area occurs at C-SW$\frac{1}{4}$-NW$\frac{1}{4}$-NW$\frac{1}{4}$ 26 31N-4E on the west side of Crane Pond Creek, at Highway F on the east side of Crane Pond Creek as has already been mentioned, and on the hill side at C9 31N-4E.

The lithology of Unit 1 below these contacts appears to be much the same. The beds along Crane Pond Creek at Highway F (underlying Unit 4) are believed to be the same set of beds that occur in the western portion of the area around Annapolis (underlying Unit 4, see above) and which belong to the Derby-Doerun according to results from residue samples.

Scattered outcrops of Unit 1 occur to the north of Minimum along Crane Pond Creek, The rocks in these outcrops carry the same coarse-grained lithology. A 20' section which occurs in the C-N$\frac{1}{2}$-NE$\frac{1}{4}$-SE$\frac{1}{4}$ 10 31N-4E was sampled for insoluble residues. Mr. McCracken of the Missouri Geological Survey examined the lithology of the original samples and the insolubles from the samples and placed them in the middle Bonneterre (?). Samples for residue studies were also taken at two other localities in the general vicinity of the area. These include 35' of samples from the south end of the hill just east of Crane Pond Creek, in the southeast corner of section 12, 31N-3E, and 12' of samples just below the south side of the Minimum bridge crossing Crane Pond Creek. The beds at these localities were also placed in the middle Bonneterre (?).

It will now be shown that the rocks where these samples were taken should agree with results from sections where Unit

1-Unit 4 contact similarly occur.

The 35' section (Unit 1) in the southeast corner of section 12 (see above) carries several unique beds of dense, finely crystalline dolomite with red to brownish gray and greenish gray patches. Very similar beds occur along Sulfur Creek in C-E½-SE¼-NW¼ 9 31N-4E where the road makes its second crossing over the creek. The beds dip here about 4 degrees north. Four feet of dense, finely crystalline dolomite occurs in the lower portion of the outcrop. The dolomite has various shades of green, red and brown patches. Thirty feet of drusy dolomite belonging to Unit 4 forms a portion of the overlying beds. These beds occur along side of the hill at a short distance to the north.

The 12' section of Unit 1 just below the Minimum bridge forms part of the Unit along the east side of Highway F in C-W½-W½-NW¼ 14 31N-4E. It is believed that a Unit 1-Unit 4 contact occurs at a short distance above these beds to the south. The rocks on both sides of the contact at these localities should belong to the Derby-Doerun since the rocks on both sides of the same contact along Big Creek valley are Derby-Doerun.

Arguments in favor of these Unit 1 beds belonging to the Bonneterre formation are the following ones:

1. Insoluble residue studies indicate such.
2. The Unit 1 beds at Minimum and to the north and south along Crane Pond Creek contain some green shaly material which is typical of parts of the Bonneterre formation.

3. The 20' of wavy flaggy beds of Unit 2 which overlie Unit 1 in section 15, 31N-4E may belong to the Davis formation. Unit 2 beds also overlie Unit 1 in section 22, 31N-4E.

b. Unit 2

Name and areal distribution:

The name Unit 2 is used here to designate the beds which underlie and overlie beds of Unit 1 and which are believed to grade laterally into Unit 1, (see "Relations with known formation" under Unit 1). They also underlie the typical massive beds of the Derby-Doerun formation. The rocks of this Unit consist of thin to massive bedded, fine to medium-grained calcareous dolomite. Wavy, flaggy beds with large calcite filled vugs characterize these beds.

It is uncertain whether these beds belong to the Davis or Derby-Doerun formation and where the contacts for these formations should be placed. For these reasons, the beds in Unit 2 have been mapped as a lithologic unit without denoting a formational name to them.

The beds of Unit 2 crop out to the north of Annapolis along Big Creek, Richland Creek and Brushy Creek. They form high bluffs along the west side of Big Creek in the NW$\frac{1}{4}$ of section 15 and the C-E$\frac{1}{2}$ of section 10. The beds occur along the bottom of Richland and Brushy Creeks where they pinch out beneath the overlying massive Derby-Doerun beds. Beds of Unit 2 also occur in the west fork of the Mine Hollow and along the south side of Sulphur Creek in section 15 just south of Minimum.

They are colored in brown on the geologic map.

Lithology and thickness:

Map Unit 2 consists predominantly of fine to medium-grained, thin to massive beds of calcareous dolomite. Some of the beds are jagged and blocky. A characteristic feature of many of the beds is the occurrence of ½" to 1" vugs containing white to very tan calcite. The vugs form conspicuous cavities on the weathered surface.

The following 42' thick section from top to bottom occurs directly below Derby-Doerun section I and shall be referred to as Unit 2 - Section I. (See figure 18).

Unit 2 - Section I

Top	M.	Cm.	Ft.	In.	
(9)	4	88	16		Thin to flaggy, wavy bedded, highly calcareous dolomite, similar to (3) with 1/16" to 1/8" calcite seams between beds; beds with rounded holes from 1/2" to 2" in diameter (these holes are former vugs filled with calcite).
(8)		76	2	6	Buff to brown dolomite with beds 1" to 2" thick; highly calcareous in places; beds jagged with projecting 1" to 2" blocks; weathered surface with 1/2" to 2" solution cavities; large solution cavities average 1½' x 2' scattered about 5' apart.
(7)		51	1	8	Bed similar to (1); brownish gray with buffy layers in places; dolomite very hard and calcareous in places.

Figure 18. Unit 2 beds along Big Creek in S½-NW¼ 15 31N-3E.

	M.	Cm.	Ft.	In.	
(6)	1	67½	5	6	Fine to medium grained dark grayish brown to brown calcareous dolomite with irregular buff calcite patches and dark drown streaks; beds average 1" to 8" thick; rock fairly hard.
(5)		91½	3		3" to 6" hard jagged beds of calcareous dolomite; dolomite grayish brown with large buff patches; vugs with calcite.
(4)		61	2		Similar to (3).
(3)	1	22	4		Buff to light brown fine to medium-grained calcareous dolomite similar to (2), but much more loosely compacted.
(2)	1	98	6	6	Thin to flaggy beds of light brown to buff, calcareous dolomite similar to (1) except for vugs containing calcite crystals; shaly dolomite seams approximately 1 mm. thick in places; beds with sparsely distributed ½" quartz and felsite fragments.
(1)		30½	1		Dark grayish brown medium to coarse-grained, hard dolomite. The bottom of (1) is approximately six feet above the water level of Big Creek.
Bottom					

A 76½' section occurs on the bluff along the west side of Big Creek in the C-E½ 10 31N-3E. This is the thickest section observed to occur in the area.

Relations with overlying and underlying rocks:

The relations of beds in this Unit with those of Unit 1 are given under "Relations to overlying and underlying rocks" of Unit 1.

The relations of beds in Unit 2 with the overlying massive Derby-Doerun beds (Unit 3) are given under "Relations to overlying and underlying beds" of the Derby-Doerun.

Relations with known formations:

Results of insoluble residues from KIDWELL's work showed that the beds in Unit 2 Section I belong to the Derby-Doerun formation. The results from the 76½" section in C-E½ 10 31N-3E showed that the beds belong to the Davis formation.

Unit 2 Section I occurs as a high bluff about one quarter of a mile west of an exposed igneous knob. The 76½' section likewise occurs as a high bluff about one quarter of a mile from the same knob, but located to the northwest of the knob. The two sections appear very similar and underlie the massive beds of the Derby-Doerun formation.

BUCKLEY and DAKE indicate that the Derby formation consists of massive beds and the Doerun formation consists of thin beds. According to R. E. WAGNER (see OHLE and BROWN, 1954), the reverse occurs (i.e., the lower part of the Derby-Doerun consists of thin beds and the upper part of massive beds). Thus, whether the beds in Unit 2 belong to the Davis formation or to the lower part of the Derby-Doerun formation is uncertain.

The following remarks have also been mentioned under "Relations with known formations" under Unit 1.

The beds of Unit 2 in the western fork of the Mine Hollow underlie coarse-grained beds with Derby-Doerun characteristics. The Unit 2 beds are very similar to the beds in Unit 2 Section I underlying Derby-Doerun Section I (insoluble residue studies showed the beds in Unit 2 Section I to be Derby-Doerun). Insoluble residue studies showed the Unit 2 beds in the Mine Hollow to be either Bonneterre or Davis. It appears that these beds belong to the Derby-Doerun formation since insoluble residue studies placed similar beds below Derby-Doerun Section I in the Derby-Doerun formation.

c. Unit 3 (Massive beds of Derby-Doerun formation)

Name and areal distribution:

The Derby formation was named for its occurrence in close proximity of the old Derby mine which is about one-half mile southeast of West Elvins, Missouri. The name "Doerun" is from the Doerun Lead Company which owned the lands just east of Elvins upon which the type section occurs. The two formations are now included together under the compound name of Derby-Doerun (BRANSON, 1945, p. 27, 28).

The Derby and Doerun formations were first described by BUCKLEY (1909, pt. 1, pp. 44-51). According to BUCKLEY, the Derby formation "is characterized by massive beds of hackley

> dolomite, which, upon weathering break down into large polygonal blocks often 20 feet in their greatest diameter... This formation has an average thickness of from 38 to 49 feet and is conformable with

> the underlying Davis formation and also with the overlying Doerun... Resting conformably above the Derby formation is a horizon (Doerun) which consists of argillaceous dolomite... The normal thickness of the Doerun formation is 50 to 60 feet... The thickness of this formation is variable between quite wide limits, owing to an uneven or perhaps uncomformable contact with the overlying Potosi formation."

In this investigation the outcrops mapped as Derby-Doerun include only those massive beds which are similar to the massive Derby-Doerun outcrops along Highway 32 near West Elvins and which fit descriptions given by BUCKLEY (1909) and DAKE (1930). The locality in West Elvins is on the hill about three-quarters of a mile from the point where Highway 32 curves to the west away from Flat River (creek) and is approximately in C-SW¼ 13 36N-4E.

As shown on the geologic map, massive Derby-Doerun outcrops occur along Big Creek, Richland Creek and Brushy Creek in the northwest half of the area, along Crane Pond Creek in the extreme southeast end of the area, and on the east side of Big Creek about one mile outside of the area to the south. The outcrops occur generally as massive beds or as massive isolated blocks about 3' to 4' thick. A distinct feature of these massive beds is the discontinuity of bedding plane joints which are usually spaced from 4" to 2' apart (see figure 20). The massive beds crop out on both large and small bluffs usually bordering the creeks.

Lithology and thickness:

The Derby formation, according to BUCKLEY, "is characterized by massive beds of hackley dolomite, which, upon weathering,

> break down into large polygonal blocks often 20 feet in their greatest diameter... Soft, porous beds alternate with those that are dense, hard and brittle... As a whole this formation is a fine-grained, crystalline, slightly calcareous dolomite... In color the dolomite varies from a light gray through yellowish gray to reddish brown."

DAKE (1930, p. 102), in describing the lithologic characteristics of the Derby, stated that "Cross-bedding is a conspicuous feature of many outcrops of the massive phases of the Derby."

The Doerun formation, according to BUCKLEY (1909, p.47)

> "consists of alternating beds of argillaceous dolomite, finely crystalline dense dolomite and soft finely porous dolomite... The bottom of the formation is characterized by a thickness of 12 feet 8 inches of very thinly bedded dolomite... About 8 feet above this there is another horizon of argillaceous dolomite which, upon weathering, also splits into thin layers. This latter horizon is 12 feet 6 inches thick... The upper 9 to 10 feet of this second thinly bedded horizon, contains many small, irregular cavities lined with minute crystals of quartz druses... Above these, hard finely crystalline dolomite beds alternate with beds of soft, finely porous dolomite which has a decided pinkish tint near the top. These beds frequently exhibit cross-bedding... The upper part of this formation is especially characterized by small quartz druses."

R. E. WAGNER, (OHLE and BROWN, 1954, p. 204, figure 2), in his general section of the lead belt area, shows the Derby as consisting of 40' of thin bedded dolomite with some shale, and the Doerun formation as consisting of 60' of massive and earthy dolomite.

The logs from 6 wells in the vicinity of Annapolis (3 wells from section 14, and 3 from section 23) show a complete thickness of Derby-Doerun to measure from 110' to 230'. Most of these logs begin about 20' to 30' below the surface and all pass through about 15' to 30' of Potosi dolomite. The total depth of these wells ranges from 391' to 768'.

Eleven other logs in the vicinity of Annapolis show incomplete sections of Derby-Doerun to measure from 85' to 185' thick. Six of the logs begin from 0' to 37' below the surface. The other five begin from 95' to 195' below the surface. The total depth of these wells ranges from 450' to 650'.

The measured sections of the Derby-Doerun on outcrops along Big Creek valley by KIDWELL (1947) range from 3' to 210' thick.

Massive beds of Derby-Doerun cap the top of the 78' bluff directly along Big Creek about one-half mile NW of Annapolis in C-W$\frac{1}{2}$-SE$\frac{1}{4}$-SE$\frac{1}{4}$ 15 31N-3E (see figure 19). The section is 28' to 30' thick and consists of massive beds overlying thin to flaggy beds. The beds strike due N to N25E and dip 4W to NW. They dip off the exposed igneous knob about $\frac{1}{2}$ mile across the creek to NE.

The following section from top to bottom occurs at this locality. This section shall be referred to as Derby-Doerun Section I.

Derby-Doerun Section I

Top	M.	Cm.	Ft.	In.	
(7)	1	22	4		Massive bed similar to (5) with discontinuous bedding plane joints spaced 1' to 2' apart; medium-grained, slightly siliceous calcareous dolomite with orange and small greenish gray patches; protrudes 4' to 6' over (6).

Figure 19. Massive beds of Derby-Doerun along Big Creek about one-half mile northwest of Annapolis in C-W$\frac{1}{2}$-SE$\frac{1}{4}$-SE$\frac{1}{4}$ 15 31N-3E. These beds overlie the Unit 2 beds shown in Figure 18.

Figure 20. Derby-Doerun outcrops in Richland Creek at C-S$\frac{1}{2}$-NE$\frac{1}{4}$ 9 31N-3E.

	M.	Cm.	Ft.	In.	
(6)	1	22	4		Massive to flaggy bedded, medium to fine-grained, calcareous dolomite similar to (4) with orange to buff and grayish brown patches; 1½' zone in center of bed well jointed along bedding planes; weathered surface similar to (4).
(5)	1	7	3-4		Massive protruding ledge with dark tan, fine-grained to medium-grained, very slightly calcareous dolomite; cross-bedded with 3/4" grooves and ¼" to ½" siliceous ridges.
(4)	2	6	6	11	Massive bedded, medium-grained dolomite with dark tan and gray patches with overall dark appearance; discontinuous bedding plane joints 4" apart in upper 2½'; weathered surface tan to brown.
(3)	1	52½	5		Medium-grained, porous, gray calcareous dolomite with two zones containing small 1 mm. aggregates of crystalline quartz; lower siliceous zone 1½" thick and 32" from bottom; weathered surface pitted to slightly grooved along layers; cross-bedded in lower 2' (see figure 37).
(2)		13		5	Bed with rock similar to (1).
(1)	1	73	5	8	Massive bedded (discontinuous bedding plane joints spaced 4" to 20" apart) medium to fine-grained, grayish brown, porous, highly

calcareous dolomite; pores buff in color, and 1 mm. in diameter; dolomitic limestone

Bottom in upper part; cross-bedded in upper 16".

Parts (1), (2), (3), (5) and (7) show a marked similarity. They crop out as massive protruding ledges of medium-grained, cross-bedded, siliceous, generally porous calcareous dolomite.

Parts (4) and (6) are similar in that they weather more easily, and they are well jointed along the bedding planes and have a blocky appearance between the joints. They are not cross-bedded and appear to be quartz free. They have pink, gray and brown patches.

Large slumping blocks from Parts (5) and (7) occur about 200' back from the bluff in the wooded area (see figure 21). The color of the unweathered surface is dull, clean looking and dark gray. Large solution hollows (see figure 22) occur in places on the surface. Some of the outcrops with these hollows give a characteristic sound when struck with a hammer. This sound, together with a generally clean dark gray appearance, was found to occur on many of the massive Derby-Doerun outcrops. These hollows resemble the Tafoni holes described in detail by POPOFF (1937) and KLAER (1956).

A very peculiar structure occurs at the top of the bluff, where Parts (5) and (7) are exposed. These consist of circular pits (see figure 23) from 4" to 1' in diameter and 2" to 6" deep with ½" to 3/4" rounded grooves trailing down the sides of the pits. Sharp narrow ridges trail down between the grooves. Very similar structures were observed on the

Figure 21. Large slumping blocks of Derby-Doerun from parts (1) and (3) at Derby-Doerun Section I (C-W$\frac{1}{2}$-SE$\frac{1}{4}$-SE$\frac{1}{4}$ 15 31N-3E).

Figure 22. Derby-Doerun outcrops showing large solution hollows. Outcrops near Derby-Doerun Section I (C-W$\frac{1}{2}$-SE$\frac{1}{4}$-SE$\frac{1}{4}$ 15 31N-3E.

Figure 23. Typical solution hollows in the massive Derby-Doerun beds at Derby-Doerun Section I (C-W$\frac{1}{2}$-SE$\frac{1}{4}$-SE$\frac{1}{4}$ 15 31N-3E).

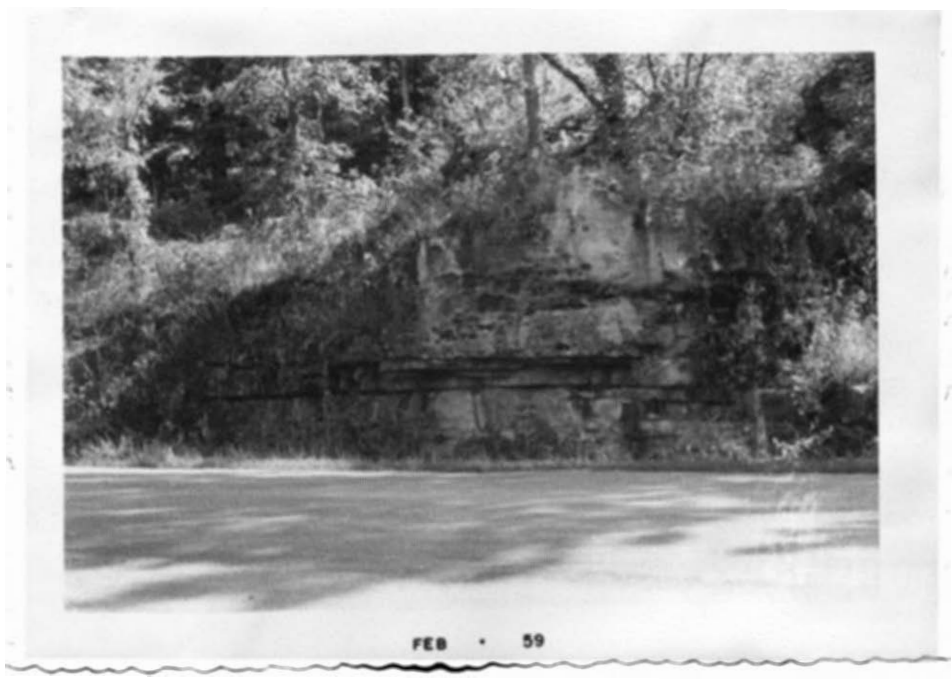


Figure 24. Massive Derby-Doerun beds along Highway 49 at Derby-Doerun Section II in C-NE$\frac{1}{4}$-SE$\frac{1}{4}$ 13 31N-3E.

massive Derby-Doerun beds along Highway 32 in the vicinity of the type section near West Elvins. A cross-section perpendicular to the grooves from a specimen from the Elvins locality reveals that nearly vertical layers of pink argillaceous dolomite alternate with more porous layers of highly calcareous dolomite. It appears that wherever weathering has progressed past the more resistant dolomite, rapid solution takes place in the more porous layers. The grooves are in the porous layers.

Outcrops very similar to those at the top of Derby-Doerun Section I occur to the north in Richland Creek (see figure 20) in C-S$\frac{1}{2}$-S$\frac{1}{2}$-NE$\frac{1}{4}$ 9 31N-3E. They are massive, slightly corss-bedded outcrops with large solution hollows on the surface.

Similar outcrops occur about $\frac{1}{2}$ mile due east of Derby-Doerun section I in C-S$\frac{1}{2}$-NE$\frac{1}{4}$ 15 31N-3E a few hundred feet from Highway 49 in the Creek which leads down to Robinson's mill. The rock consists of a tan medium-grained, porous, highly calcareous dolomite with pink and tan stains on the dolomite crystals. Gray dense layers, approximately 1/8" thick, spaced $\frac{1}{2}$" apart, form ridges of the crossbeds on the weathered surface.

About 100' just south of Robinson's mill, a 2$\frac{1}{2}$' to 3' massive slab-like bed crops out directly along Big Creek. The bed strikes N80E and dips 5S. The dip is off the exposed igneous knob which occurs $\frac{1}{4}$ mile to the north. The bed consists of fine to medium-grained, porous, dark tan calcareous dolomite with 1/8" gray layers spaced $1\frac{1}{2}$" apart.

On the other side of the knob and about 1 mile further to the north, massive beds overlying beds of Unit 2 occur directly along side of Highway 49 (see figure 24) just south of the sharp curve (Dead Man's Curve) in the road in C-NE$\frac{1}{4}$-SE$\frac{1}{4}$-13 31N-3E. The section is approximately $16\frac{1}{2}$' thick with nearly horizontal beds.

The following section from top to bottom occurs at this locality, and shall be referred to as Derby-Doerun Section II.

Derby-Doerun Section II

Top	M.	Cm.	Ft.	In.	
(3)	1	$52\frac{1}{2}$	4-6		Massive beds similar to (1).
(2)	1	$52\frac{1}{2}$	5		Massive bed similar to (1)
(1)	1	98	6	6	Massive bed with solution hollows on surface; cross-bedded, rock of medium-grained, gray, dolomite on fractured, unweathered surface in the lower part; alternating layers of gray dolomite and tan, slightly porous dolomite on fractured unweathered surface in center of bed; gray layers $\frac{1}{4}$" thick and 1" apart and form the ridges on the cross-beds; thick brown porous layers are orange and highly calcareous where weathered and form grooves on cross-beds; small patches of quartz druse in places throughout bed.
Bottom					

Most of this section may be followed for $\frac{1}{4}$ mile to the south along Highway 49. A 14' section occurs $\frac{1}{2}$ of a mile south of Derby-Doerun Section II, just inside of the gate to Bowes farm. Cross-beds occur throughout 8' of the section with cross-beds half way up in the section dipping up to 15 degrees to the southeast.

The contact between the massive and the thinner underlying beds may be followed to the south where the dip increases as the knob is approached. A 5' section of scattered cross-bedded outcrops occurs at the end of the open field a few hundred feet up the follow from Highway 49 in C-N$\frac{1}{2}$-N$\frac{1}{2}$-SW$\frac{1}{4}$ 11 31N-3E. The rock consists of buff colored, slightly porous calcareous dolomite with 1/8" layers of gray to grayish brown dolomite spaced $\frac{1}{2}$" to 1" apart. The gray layers thicken to $\frac{1}{2}$" in places. The gray dolomite forms the ridges and the buff calcareous dolomite forms the grooves in the cross-beds on the weathered surface.

In C-SW$\frac{1}{4}$-NE$\frac{1}{4}$-SW$\frac{1}{4}$-SW$\frac{1}{4}$ 11 31N-3E just east of the knob at elevation 790' on the hill a 10' section of massive cross-bedded outcrops dip into the hill at 11 degrees to the ENE. The section consists of two massive beds, each approximately 4' thick, of medium to coarse-grained gray calcareous dolomite. A 1' zone of quartz druse occurs 3' up from the base and a 2$\frac{1}{2}$' zone of quartz druse occurs at 4' up from the base.

The rock is porous in places with the pores surrounded by tan calcite. The weathered surface is pitted with $\frac{1}{4}$" to $\frac{1}{2}$" pits and shows the grooves and ridges of the cross-beds. Outcrops further up the hill at 810' elevation, which are believed to be the same beds, contain abundant quartz druses.

South of Derby-Doerun Section I, massive bedded Derby-Doerun crops out in several places.

A 40" section occurs on the north side of the Brushy Creek approximately 150' west of the Creek ford and just west of the center of the section line between sections 15 and 16, 31N-3E. The dip is 1 degree to the south. The section consists of two massive beds of medium-grained, slightly calcareous dolomite. Cross-beds dip up to 20 degrees to the south.

To the southeast along the west side of the road in C-SW¼ 15 31N-3E at 680' elevation massive cross-bedded outcrops consist of gray slightly buff and porous dolomite with elongate grooves at the surface. Quartz druses, similar to those at Derby-Doerun Section I-(5), occur at the top of one of the beds. Similar beds occur across the road on east side of the hill about ¼ of a mile to the southeast.

Massive, faintly cross-bedded Derby-Doerun occurs in SW¼-NE¼-NW¼ 22 31N-3E along the hill side on the north side of the road next to Kallemeyer's house (see figure 25) which has a large white wooden fence at the front. The rock consists of medium-grained, light gray to brownish gray calcareous dolomite with pink spots in places. The typical solution holes and bedded quartz occur on these rocks.

Very characteristic massive bedded Derby-Doerun crops out to the southeast on the bluff overlooking Big Creek and about 40' above Big Creek in C-S½-N½ 22 31N-3E. The bed, which is about 4' thick, is jointed in places along bedding planes and has a 2" zone of small 1 mm. quartz druses. It strikes N42E

Figure 25. Cross-bedded Derby-Doerun beds on the north side of the road just west of Annapolis in C-NW$\frac{1}{4}$ 22 31N-3E.

Figure 26. Massive isolated block of Derby-Doerun in the southeast end of the thesis area on the east side of the road in C-N$\frac{1}{2}$-S$\frac{1}{2}$ 36 31N-4E.

and dips about 1 degree to the NW. The dip is off the exposed porphyry knob, which lies to the south. The rock consists of medium-grained reddish brown, porous calcareous dolomite with minute red porphyry fragments. Cross-beds are faintly distinct. The characteristic solution holes are faintly shown. This bed overlies dolomite containing cellular quartz druses.

Massive cross-bedded, very typical Derby-Doerun crops out directly along the east side of Big Creek about one mile south of the thesis area in C-S½ 6 30N-4E. The rock consists of medium-grained, yellowish-tan, porous, highly calcareous dolomite with pink and yellow stains on the dolomite crystals lining the pores. These beds overlie thinner beds. They strike N70W and 10N with the dip off of the igneous knob which is about three quarters of a mile to the south.

The outcrops in section 36 31N-3E in the southeast part of the area consist of massive step-like beds and one large 4½' thick isolated block (see figure 26).

Relations with overlying and underlying rocks:

The typical massive bedded Derby-Doerun was found to overlie two distinctly different lithologies. They include the fine to medium- grained, thin to flaggy, wavy beds of Unit 2 and the very massive beds of coarsely-grained hard, slightly vuggy, often glauconitic dolomite beds of Unit 1.

The relations between the massive bedded Derby-Doerun and the underlying beds of Unit 1 are given under "Relations to underlying and overlying beds of Unit 1."

Derby-Doerun Section I overlies 16' of thin to flaggy beds of fine-grained calcareous dolomite of Unit 2. The contact between these beds and the massive bedded Derby-Doerun appears to be conformable. The thin wavy beds crop out along Brushy and Richland Creeks just below the massive Derby-Doerun. They also occur just below Derby-Doerun Section II on the east side of Big Creek. The contact between the thin to flaggy beds and the massive bedded Derby-Doerun was drawn on the basis of differences in lithology and bed thicknesses.

Relations with known formations:

The outcrops mapped as Derby-Doerun include only those massive beds which are similar to the massive Derby-Doerun outcrops along Highway 32 near West Elvins and which fit the descriptions given by BUCKLEY (1909) and DAKE (1930). The locality in West Elvins is on the hill about three-quarters of a mile from the point where Highway 32 curves to the west away from Flat River (creek) and is approximately in C-SW$\frac{1}{4}$ 13 36N-4E.

d. Unit 4

Name and areal distribution:

The name Unit 4 is used here to designate the rocks which directly overlie beds of Unit 1 and/or Unit 2, and/or Unit 3, and which form the upper part of the exposed section. The lower portions of this unit are believed to include beds which are laterally equivalent to the massive Derby-Doerun beds, but which more nearly posses the lithologic characteristics of Unit 4.

The rocks of this unit occur as very massive, often vertically jointed beds of medium-grained dolomite, with small irregularly shaped vugs. Quartz druses are abundant in places, which may have been one of the main criteria for DAKE (1930) when he assigned these beds to the Potosi formation. As pointed out above, no indications of an actual unconformity was found during mapping for this thesis. The transitions between Units 3 and 4 even speak against an unconformity. The lowest beds of Unit 4 appear locally to form part of the Derby-Doerun formation. Because the location of formational contacts is uncertain, sections showing Unit 4 type of lithology were mapped as a lithologic unit without denoting a formational name to them.

Lithology and thickness:

The rocks of this unit are characterized by very massive beds of medium-grained dolomite with bedding planes which are often difficult to distinguish or are non-existent. Vertical jointing frequently occurs in these beds where they have been observed to overlie Unit 1. The weathered surface is usually slightly pitted, being the result of solution around small irregularly shaped vugs. Surface outcrops are often pinnacled. Large masses of thinly cellular quartz druse, measuring up to 3' in diameter, have been observed in the upper part of the section. Where this unit comes in contact with Unit 1, there is a distinct change in soil coloration from brown to reddish brown. This is considered to be especially well shown on both ides of Crane Pond Creek along Highway F. Dolomite in the eathered outcrops is usually friable and often weathers with conspicuous "sandy" appearance. When observed under the and lens, this "sandy" weathered product appears as numerous ndividual rhombohedral grains of dolomite. Unit 4 also ncludes in places beds of hard dense fine-grained, blocky olomite. Such included beds occur in the section along Crane ond Creek and Brush Creek in the southeast portion of the area.

The section in C-SE¼ sec. 36 31N-4E on the east side of rane Pond Creek measures 68' in thickness and is nearly con- inuous from 10' above the creek to 30' below the top of the ill. The entire section was sampled for inslouble residue studies. The results placed this section in the Derby-Doerun ormation. This section from top to bottom is described below:

Unit 4 - Section 1

op	M.	Cm.	Ft.	In.	
(20)	1	52½	5		Similar to (15) except brownish in color, highly siliceous with abundant quartz druses.
(19)	1	4	3	5	Pitted, craggy dolomite; ledge former, protrudes 2' out; rock similar to (15) with glauconite.
(18)	1	52½	5		Brownish, reddish and gray dolomite with sparsely distributed 1" to 2" quartz druses; area around quartz druses looks like cement patches; one upper 6" bed, one middle 1' bed, one lower 3½' bed.

	M.	Cm.	Ft.	In.	
(17)	2	28	7	6	Cover.
(16)	1	83	6		Hard, dense, medium to coarse-grained, dark gray dolomite; pink in places.
(15)	1	22	4		Same as (11).
(14)	1	55	5	1	Fine to medium-grained dolomite with 1/8" vugs.
(13)		79	2	7	Medium-grained dolomite ¼" calcite-filled vugs.
(12)		23		9	Medium to coarse-grained light gray calcareous dolomite with calcite in vugs.
(11)		38	1	3	Fine-grained to dense pink dolomite.
(10)		76	2	6	Fine-grained, pink dolomite with small reddish 1 mm. vugs.
(9)		13		5	Reddish thin bedded coarse-grained dolomite conglomerate; breaks easily.
(8)	1	83	6		Light gray to white, coarse-grained calcareous dolomite with small vugs mostly in lower portions.
(7)		41	1	4	Medium to coarse-grained dolomite; gray with minute pink spots.
(6)		30½	1		Medium-grained, brownish gray dolomite.
(5)		10		4	Medium to fine-grained, light pink to buff "sandy" dolomite; bedding lines not continuous.
(4)	3	35	11		Cover.

	M.	Cm.	Ft.	In.	
(3)		46	1	6	Massive bedded (one 10" bed and one 8" bed), fine-grained, slightly "sandy" dolomite, gray with buff patches.
(2)		30½	1		Cover.
(1)		66	2	2	Massive, non-bedded, medium-grained, dark gray with pink patches; weathered surface smooth.
Bottom					

The bottom of (1) is 10' above the creek.

The beds in this section are generally greater than 3' in thickness. They are distinctly cross-bedded in places near the top of the section. Much of the rock is buff to pinkish in color.

The section at NW¼-SE¼ 35 31N-4E on the hill on the south side of Brush Creek measures 144' in thickness with the bottom of the section about 6' above the stream.

Masses of rusty, thinly cellular quartz druse measuring up to one foot in diameter occur with dolomite 110' up in the section near the C-E½-NE¼ 31N-4E on the hill on the south side of the Brush Creek just east of the small hollow. These large masses of quartz druse are believed to occupy the same stratigraphic position in the section as the cellular druse in dolomite along the hillside on the east side of Big Creek near Duncan's agricultural limestone quarry (see figure 40) in the extreme southeast corner of the section 36 31N-3E. The druse in the dolomite near Duncan's quarry (see figure 29) measures about 3' in diameter and is located in the wooded area just northwest of the cleared area on the northwest side of the quarry on the side of the hill at bearing N 10-15 W from the quarry truck shack (shack is just east of creek). It is approximately 60' higher in elevation (altimeter measurement) than the quarry shack. This would be about 65' to 70' up from Big Creek. The dolomite with which the druse is intimately associated is fine-grained and brown, with numerous white streaks of quartz on the fractured surface. The color of the dolomite on the fractured surface varies in places from brown to very dark gray to orange. Similar quartz druses occur to the south on the hill side along the east side of Big Creek at C-E½ 6 30N-4E. The section from the creek to the druse measures 70' and consists of massive beds of dolomite and cover. The dolomite on the fractured surface is very light tan with small brown unfilled vugs. The dolomite is friable or "sandy" on the weathered surface. Beginning at 70' up in the section, 10' to 15' of massive beds of brownish gray to reddish brown dolomite are associated with large masses of cellular quartz druse.

The rusty thinly cellular, siliceous masses with quartz druse from the above localities differs from typical Potosi druse in that Potosi druse has very thick and banded cell walls, with much fewer and larger cavities. The Potosi druse has a strong structure and a heavy appearance. The typical Potosi druse has been found among the residuum along the hill sides in the thesis area. Such druse was apparently once contained in dolomite which occupied a much higher position in the section.

Relations with overlying and underlying rocks:

The relations between beds of Unit 4 and the underlying beds of Unit 1 are given under "Relations with overlying and underlying beds of Unit 1."

A contact between Unit 2 and Unit 4 occurs on the east side of Sutton Hollow Creek just north of the creek ford in the extreme northwest corner NE¼-NE¼ 35 31N-3E. The contact is conformable and is marked by an abrupt change in lithology.

One locality in the area under investigation shows that the massive beds of the Derby-Doerun formation grade into beds of Unit 4. In C-36 31N-4E, a massive block of Derby-Doerun (see figure 26) occurs directly along the east side of the road. Step-like beds of Derby-Doerun occur about 1/8 mile to the south along the south side of the road. Unit 4 beds occur along Highway F just north of the crossing of this side road with Highway F.

Unit 4 beds overlying Unit 1 beds showing strong similarities to beds in Derby-Doerun section I occur on the north side of the hollow in C-SE¼ 15 31N-3E. On the south side of the hollow, these beds show Unit 4 lithology.

Relations with known formations:

The beds in Unit 4 must be the beds which DAKE (1930) considered to belong to the Potosi formation although DAKE does

Figure 27. Unit 4 outcrops along Highway F at SE$\frac{1}{4}$ 28 31N-4E. The pits are originally irregularly shaped vugs somewhat enlarged by Tafoni-type weathering. They are particularly abundant in one bed but occur in various amounts all through Unit 4.

Figure 28. Unit 4 pinnacles near the top of the hill in C-N$\frac{1}{2}$-SE$\frac{1}{4}$ 36 31N-4E. For description see Figure 27 and text.

Figure 29. Drusy masses of cellular silica attached to and inside dolomite near Duncan's agricultural limestone quarry at extreme southeast corner of section 36 31N-3E.

not mention any specific locality. There is no higher sedimentary unit in the area, so there is no choice with regard to DAKE'S statement.

KIDWELL (1947) mapped these beds as belonging to the Derby-Doerun formation.

As has already been stated under "Relations with overlying and underlying beds" in Unit 4, beds near the base of this Unit show similarities to the typical massive beds of the Derby-Doerun formation.

If it is assumed with KIDWELL that these beds of Unit 4 belong to the Derby-Doerun, the very large thickness in the southern part of the area, as explained below, is unusual.

From the position of the exposed igneous knobs and the attitude of the strata and the depths obtained from well logs, it is found that a rather large, nearly semi-circular sedimentary basin covering about 20 square miles occurs, occupying the whole south central portion of the thesis area and in the area to the south. The area may be outlined by drawing a line from the Vulcan lookout tower (west side of sec. 4, 30N-3E) to the town of Brunot (corner Iron County, Wayne County, and Madison County) to the south end of Stony Mountain and back to the Vulcan lookout tower. Duncan's quarry occurs near the center of the west half of this area (SE corner 36 31N-3E).

One St. Joseph Lead Company well occurs about two-thirds of a mile to the east of the quarry. The log from this well shows the top of the Bonneterre forma tion to be at 26' above sea level. The logs from wells to the north and east show the top of the Bonneterre formation to range from 52' to 249' above sea level.

The dolomite at the quarry goes up over the 700' elevation mark. Typical Potosi druse occurs higher on the hill in the residuum. Assuming that the top of the Bonneterre in the section below Duncan's quarry occurs at an elevation similar to that of the closest well (i.e., 26' above sea level) then the thickness of the overlying Davis and Derby-Doerun formations at the quarry is over 674'. If a round figure of 100' elevation above sea level is used for the top of the Bonneterre below the quarry, this still leaves a thickness of over 600' for both formations.

The section at Duncan's quarry was sampled for lithology and insoluble residue studies. Results from these studies placed the beds in the Derby-Doerun formation.

The lithology throughout the exposed section at the quarry appears to be much the same with light and medium gray to tan medium-grained dolomite. The upper part of the section carries the quartz druse in the large masses of thinly cellular silica.

The typical Potosi residuum at the top of the hill indicates that Potosi dolomite occurred at one time higher in the section.

The relationship between the Doerun and Potosi formations on the hills near the Derby-Doerun type section as described by BUCKLEY (1909) will now be considered.

On the hills along Highway 32 near West Elvins, BUCKLEY (1909, pt. 2, pl. XLVIII) shows the top of the Doerun formation to end where the dolomite ends and where the heavy Potosi residuum begins. The Potosi residuum caps most of the hill tops. The normal thickness of the Doerun over most of the area is about 60'. In one place 120' of Doerun occurs below the residuum. This, according to BUCKLEY, is believed to be due to faulting.

From this relationship between dolomite and residuum, it appears that an unknown thickness of Doerun has been dissolved out with the true thickness of the formation probably greater in many places than is actually shown on BUCKLEY'S map.

Paleontology:

Only one fossil (see figure 31) was found in Unit 4 in the area under investigation. The fossil was found by Professor Amstutz during a short visit to the area. The location is on the bluff along the sharp curve in Highway 49 at C-SE¼ 15 31N-3E. Figure 30 shows the outcrop, with the hammer indicating where it occurs in the section.

Professor Spreng prepared and sent the fossil to the United States Geological Survey for identification.

The following is quoted from the report prepared by Ellis L. Yochelson of the Paleontology and Stratigraphy Branch of the United States Geological Survey:

> The specimen submitted is a bellerophontid gasteropod belonging to the genus _Cloudia_. It is quite similar to the type and only known species _C. buttsi_, and may be

Figure 30. Unit 4 beds along Highway 49 at C-SE$\frac{1}{4}$ 15 31N-3E. Hammer shows location where fossil gastropod *Cloudia buttsi* was found.

Figure 31. Fossil gastropod *Cloudia buttsi*. Location pictured on Figure 30.

conspecific, but in-completeness of the specimen submitted prevents conclusive specific comparison.

Cloudia (J. B. Knight, 1947, Smithsonian Miscellaneous Collections, vol. 106, no. 17), is known only from the southern Appalachians. It occurs there in the "lower part of the middle third of the Copper Ridge dolomite". This specimen extends the geographic range of the genus and it would be useful if it were deposited in the collections of the U. S. National Museum.

The fossil has been donated to the museum.

Since the occurrence of this fossil is new to the area west of the Appalachians, it could not be used for correlation with known formations of Missouri. BUTTS (1926, p. 87) states the following: "...the Copper Ridge dolomite is known to be represented in Missouri by beds which, according to Ulrich, lie between the Eminence and Proctor dolomites of the Missouri section."

3. Residuum

Residuum consists of relatively insoluble matter left in place after the sedimentary beds have undergone weathering. Residuum may be composed of cherts, clays, etcetera, which were formerly contained in carbonate rocks. It may consist of sandstone which once occurred between carbonate beds. In this case the sandstone occurs, if not destroyed by weathering, as slumping blocks along the hillsides. Heavy residuum may result when a thick carbonate section carrying abundant cherts, etcetera, is undergoing solution more rapidly than mechanical erosion.

Residuum covers over 75 percent of the area under investigation. It borders many of the creeks and occurs between scattered sedimentary outcrops on steep hillsides along main drainage valleys. Residuum occurs throughout the elevated portions of the area where igneous rocks are not exposed. Thus, large areas on both sides of the three main divides (see "Topography and Drainage" under "GEOGRAPHY") are heavily underlain with residuum. The origin and nature of residuum in southeast Missouri has been described in detail by DAKE (1930) and others, and the observations made for this thesis are mainly based on his criteria.

Most of the residuum in and around the Annapolis area is derived from the Cambro-Ordovician formations above and including the Derby-Doerun formation. Residuum occurring along the three main divides may be derived from formations higher up.

Rusty, thinly cellular chert with quartz druse is derived from the Derby-Doerun formation. Reddish brown clay weathers out of the siliceous masses. The siliceous masses with thick cell walls and quartz druse are derived from the Potosi formation. Red clay is contained in these masses also. The small cherts and chert masses with lenticular holes are derived from the Eminence formation. Boulders of chert and boulders of limonite with chert (see "Iron" under "ECONOMIC RAW MATERIALS") are probably derived from the Gasconade formation. The sandstone blocks (see "Building Stone" under "ECONOMIC RAW MATERIALS") with and without ripple marks are derived from the Gunter sandstone or the Roubidoux formation.

Bedded chert and bluish gray chert concretions occur near the top of the hill along the road in SW¼ 20 31N-4E. It is uncertain to what formation these cherts belong.

The residuum has a wide variation in thickness. Logs show thicknesses up to 95'. Many of the wells were not logged for the first 100' to 200'. The unlogged portions of some of these wells are probably due to large thicknesses of residuum.

No attempt was made to differentiate different types of residuum during mapping, although this would be an interesting topic in itself. It has all been mapped as one unit and is colored in yellow on the geologic map.

4. Alluvium

Alluvium occurs along creeks and valleys and consists of eroded residuum and igneous rock fragments partly cemented by colloidal or chemical precipitates. The alluvium along Crane Pond Creek near the Minimum bridge contains abundant fragments of porphyry. Some of this is derived from the igneous knob to the north which juts into the creek.

Large areas of alluvium occur on the flood plain along Big Creek directly south and east of Annapolis. The thickness of the alluvium layers or lenses apparently varies in a wide range. Thicknesses are uncertain since the drill logs do not show this information.

Alluvium is not shown on the geologic map. Instead, the sedimentary rocks which apparently underlie the alluvium have been projected across the valleys. This gives a clearer picture of the mapped sedimentary units although in some places the projections may not be entirely true.

IV. STRUCTURE

1. Igneous Rocks

Structures observed in the igneous include massive porphyritic rhyolite flows, primary flow layers within the porphyry, joints and faults. The one occurrence of diabase may form part of a sill.

a. Massive flows

Massive flows are shown in figure 32 and plate 1. Figure 32 shows a massive flow slab on the south side of Stony Mountain. The slab dips slightly to the east. The included primary flow layers dip with the slab. One set of joints roughly parallels the flow layers and delimits the flow mass. The upper part of the slab shows weathering by surface exfoliation. The lower part shows blocks which have weathered out along joints.

Plate 1 shows massive flows in sections 19 and 20 31N-4E. The flows dip gently to the NNW.

b. Primary flow layers

Primary flow layers occur in most of the rocks. Pronounced flow layering occurs in the rocks on Grassy Mountain. The flow layers in the rocks on Grassy Mountain generally average one-eighth inch thick and consist of quartz layers enclosed on both sides by a thin layer of fine-grained orthoclase (see "Reddish brown to bluish gray porphyritic rhyolite with pronounced flowage" under "Precambrian Igneous Rocks").

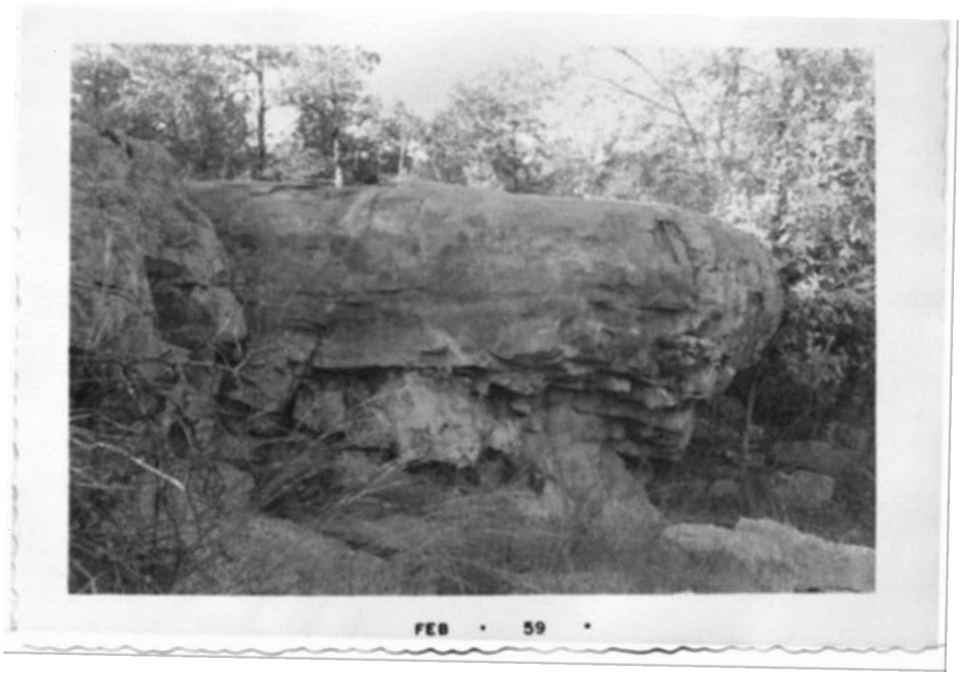


Figure 32. Massive flow slab on south side of Stony Mountain at C-W$\frac{1}{2}$-W$\frac{1}{2}$ 19 31N-4E.

This type of structure is pictured in figure 7.

Overlay 1 shows the attitude of flow layers, lines and bands.

c. Joints

Joint Diagrams 1 to 3 are point diagrams of joints from three main areas in the thesis area. Diagram 4 shows 165 joints from the entire area. According to BILLINGS (1954, p. 110), the points are the poles of lines through the center of a sphere. The lines are perpendicular to the planes of the joints. The joint plane passes through the center of the sphere. Only one pole is necessary for illustration. The southern hemisphere is used in the diagrams. One pole for each joint falls on the surface of the southern hemisphere and may be projected on a horizontal plane which passes through the center of the sphere. The scale shown on the diagrams is used for this purpose.

Joint Diagram 1 shows 101 joints from the U shaped igneous area in the north central portion of the thesis area. Most of the joints from the west leg of the U (Grassy and Stony Mountains) dip to the west. Most of the joints from the east leg of the U (unnamed knobs) dip to the east.

Two contour diagrams have been prepared. The LOWE (1946, p. 1215) method was used for contouring.

Contour Diagram 1 shows the joints from Joint Diagram 1 of the U shaped igneous area in the north central portion of the thesis area. The diagram shows that most of the joints

Figure 33. Porphyritic rhyolite from the south side of Stony Mountain at C-W$\frac{1}{2}$-W$\frac{1}{2}$ 19 31N-4E showing widely spaced joints dipping gently to the right of the photo. The joints parallel the flow layers. The flow layers are not visible in the photo.

Figure 34. Aerial photo showing main joint sets on Grassy Mountain in upper right portion of the photo.

dip very steeply. It also shows that the steep joints follow a somewhat N-S and E-W pattern. One main set strikes just east of north. Another main set strikes just north of west or 90 degrees away from the other main set. Steeply dipping cross joints are present, but less abundant.

These 101 joints have been uniformly taken over the U shaped area and probably are a fair representative sample.

Contour Diagram 2 shows 165 joints from Joint Diagram 4 over the entire area. The same general distribution of joints is present. Joints dipping from 40 to 60 degrees are more abundant than in Contour Diagram 1 and probably show the beginning of a pattern for these joints.

A minimum of 300 or more joint measurements over the entire area would probably have to be made in order to determine conclusively any definite pattern over the entire area.

d. Faults

One recognizable steeply dipping normal fault occurs in the igneous rocks in the area. It is located in the NE¼ 20 31N-4E (see plate 1 and figure 35). The aerial photos show that the massive flow layers on the northeast side of the fault plane have been faulted downward. An aerial photo which was taken during the winter shows a high concentration of trees along the fault line.

A similar line also in a wooded area occurs to the east. This line is also somewhat curved and parallels the above described fault (see plate 2 and figure 36), and therefore is

Plate **/**. Areal photograph showing igneous rocks located in sections 19 and 20 T31N-R4E. All the white areas along the hills represent outcrops of porphyritic rhyolite.

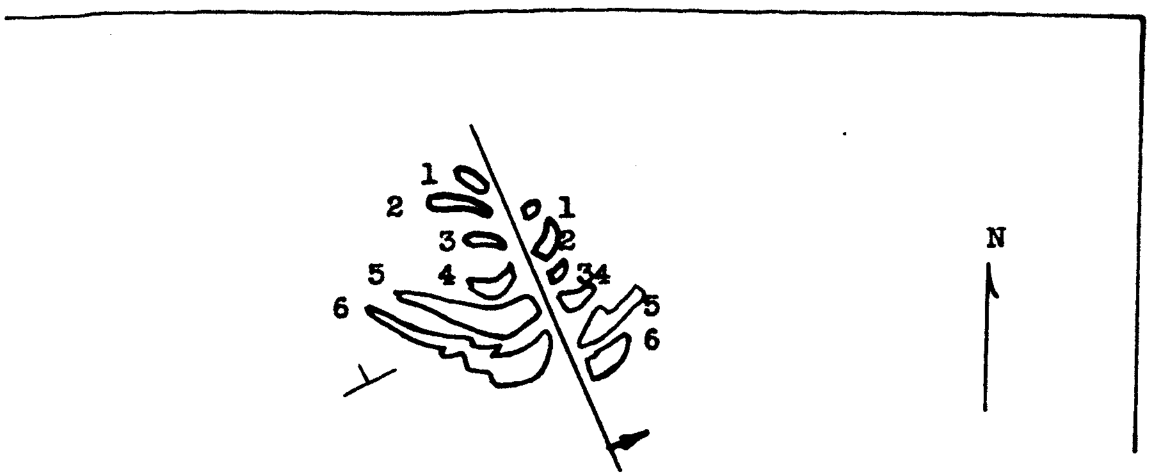


Figure **35**. Diagram illustrating faulted flow layers in east side of Plate **/**.

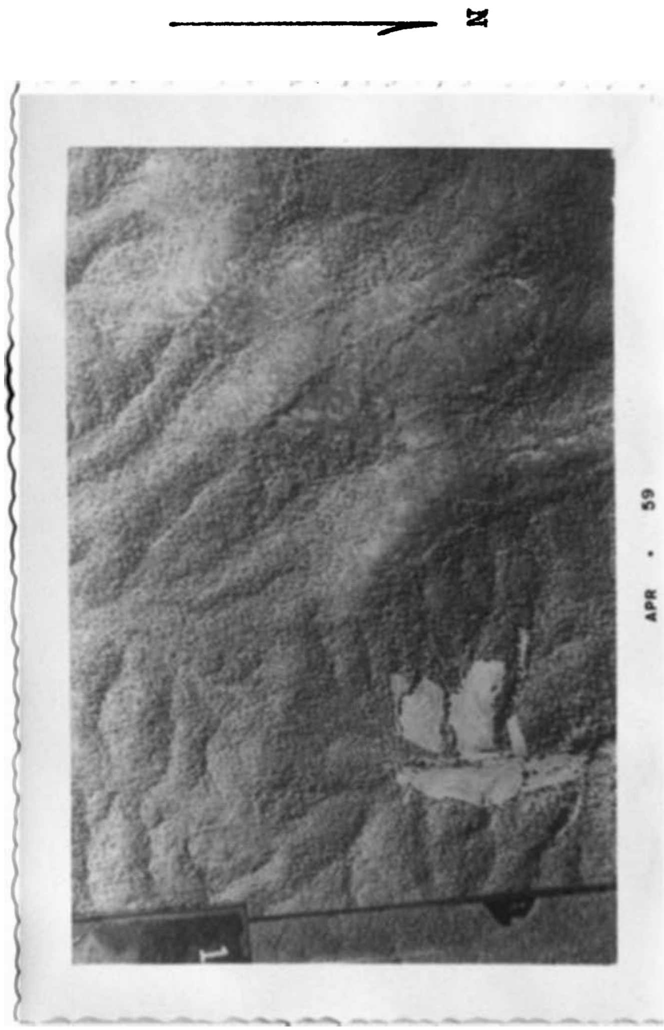


Plate 2. Areal photograph showing faults in igneous rocks located in sections 20 and 21 T31N-R4E.

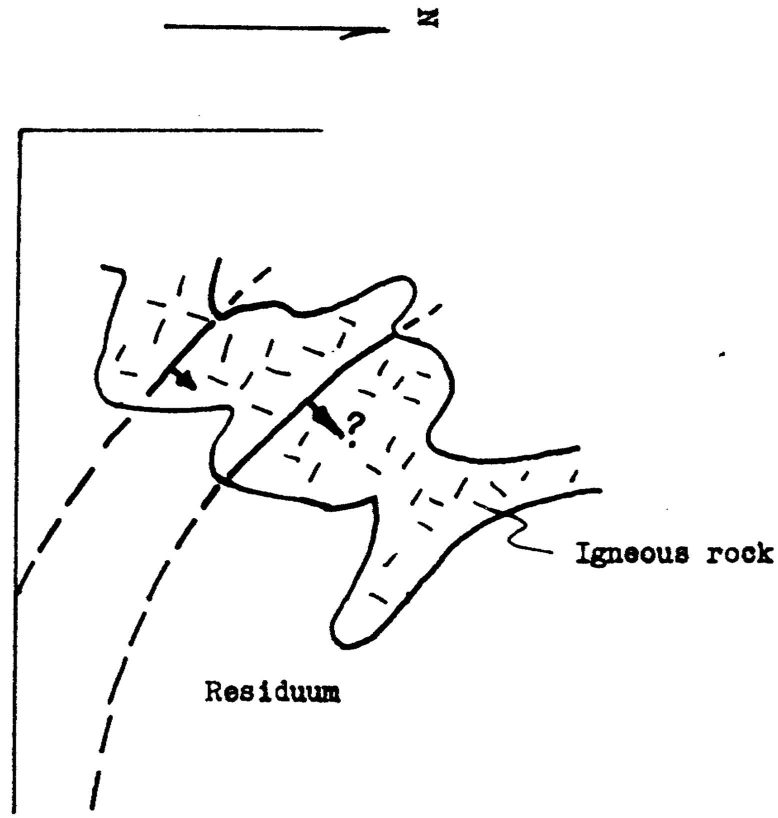


Figure 36. Diagram illustrating faults in igneous rocks and residuum (see Plate2).

considered to be another fault.

No recognizable displacement was observed in the flow layers, but neither of these faults were actually searched for in the field, because the lines on the photographs were only seen after the field mapping. It is thus not known whether there are outcrops along the fault lines and whether these faults can actually be observed.

The age of these faults is not known, but some rejuvenation may have taken place during post Upper Cambrian time since valleys trend for a considerable distance along the line of the faults into the residuum (see plate 2).

The origin and age of the joints and faults is uncertain from the little field work done so far. However, the fact that they run through different flow types and layers speaks against a cooling contraction origin. The size of any horizontal cooling pattern could never excede the vertical thickness of a flow. These observations are only to be reconciled with later tectonic adjustments. These were probably of a vertical gravity nature and from analogies to the most common tectonic activities in Precambrian time, they may well represent incipient polygonal fracture patterns.

e. Diabase intrusion

The linear outcrops of diabase (see also "Diabase" under "Precambrian Igneous Rocks") which occur just north of Highway C in NE¼ 24 31N-3E, are believed to form part of a sill or dike where the diabase has intruded porphyritic rhyolite.

Although a contact was not found, the rhyolite near the diabase is altered and shot through with fractures.

Most of the feldspar phenocrysts in the rhyolite have altered to quartz and clay minerals. The fractures are filled with calcite and quartz and abundant epidote.

2. Sedimentary Rocks

The structure in the sedimentary rocks includes the following:

1. beds dipping quaquaversally away from the Precambrian rocks,
2. joints,
3. cross-bedding and
4. solution hollows.

a. Attitude of the beds

Overlay 2 shows the attitude of the sedimentary rocks. As can be seen, beds dip away from exposed and apparently buried igneous highs.

Some beds in the lower part of the section lap on to the igneous knobs. The remaining beds, if extended from their outcrops, would cover the knobs. Beds of Unit 1 along the east side of Crane Pond Creek in NE¼-SW¼ 26 31N-4E lap directly on to the porphyry. The dolomite contains porphyry fragments and grades laterally into arkose and conglomerate.

Beds dip up to 20 degrees where they occur close to the knobs. The beds are generally horizontal or dip up to 5 degrees or less where they occur about one-half mile or more away from the knobs and where their attitude is apparently unaffected by subsurface Precambrian highs.

Buried knobs may be predicted where the beds show abrupt changes in dip without seemingly showing dips off nearby exposed igneous knobs. These criteria were used in a previous thesis at the Missouri School of Mines, on buried knobs in an adjacent area (see ZARZAVATJIAN, 1958). Buried knobs apparently occur in the following places (see also "Topography and Drainage" under "GEOGRAPHY"):

1. east of Minimum in NW$\frac{1}{4}$ 14 31N-4E,
2. C-E$\frac{1}{2}$ 9 31N-4E,
3. SW$\frac{1}{4}$ 10 31N-4E,
4. C-W$\frac{1}{2}$ 15 31N-4E and
5. SW$\frac{1}{4}$ 2 31N-4E.

The dip of the beds is believed to be due predominantly to the slope of the sediments during deposition (see DAKE and BRIDGE, 1930). With regard to compaction BRIDGE (1930, p. 156) states that limestones are only slightly compacted and therefore add little to the total dip.

b. Joints

Joints occur in the sedimentary rocks in most of the outcrops. Joint sets and systems which have been recognized include rectangular joints, strike and dip joints, diagonal joints and bedding plane joints.

Straight, well developed, closely spaced, nearly vertical rectangular strike and dip joints occur in the sediments overlying buried extensions of the exposed knobs. Such joints near exposed igneous knobs occur in the following places:
(1) along the bottom of Crane Pond Creek on section line between sections 14 and 23, 31N-3E,

(2) along creek bottom in C-E½-SE¼ 22 31N-3E,

(3) in creek bottom, west fork Mine Hollow in C-NE¼-SE¼-SE¼ 14 31N-3E, and

(4) in Big Creek, just below dam in NE¼ 15 31N-3E.

Warped beds with closely spaced rectangular joints are believed to be useful in predicting buried knobs near the surface in localities distant from exposed knobs. If this criterion is correct, buried knobs also occur near the surface in the following places in addition to the above mentioned:

(1) along Sutton Hollow Creek bottom on the north side of the creek ford on section line between sections 26 and 35 31N-3E and

(2) along Richland Creek in C-E½-SW¼-SW¼ 4 31N-3E.

In these localities, the criterion for buried knobs described above also applies.

Diagonal joints frequently accompany the rectangular joints. This is especially well shown at the above locality (1) along Crane Pond Creek bottom.

Bedding is generally thinner in these localities. Beds usually range from 2" to 5" in thickness.

Discontinuous bedding plane joints are developed in the massive Derby-Doerun beds (see figure 26).

Strike joints everywhere are well developed in Unit 4 beds where they directly overlie the Unit 1-Unit 4 contact (see "Relations with known formations" under Unit 1 for location of Unit 1-Unit 4 contact). Strike joints are also

Figure 37. Cross-bedding in the Derby-Doerun at Derby-Doerun Section I. The ridges in the cross-beds consist of quartz and may represent common calcareous cross-bedding preserved by silica.

developed in Unit 4 beds along Crane Pond Creek. The joints are generally spaced one or more feet apart and dip steeply in the direction opposit to the dip of the bedding.

c. Cross-bedding

Cross-bedding (see figure 37) occurs in the massive beds of the Derby-Doerun formation. Only portions of sets have remained distinct after recrystallization. It is uncertain whether the arrangement of the sets indicates that they belong to the tabular or lenticular types.

The outcrops generally show one or more discontinuous sets of cross-beds. In some outcrops they are faintly distinct; in others they stand out clearly as bold ridges and grooves. Silica forms part of the laminae in the cross-beds in figure 37. Along Highway 49, just south of Dead Man's Curve in C-E$\frac{1}{2}$-E$\frac{1}{2}$-SE$\frac{1}{4}$ 3 31N-3E, the massive Derby-Doerun outcrops have cross-beds in which the ridges are composed of dense gray dolomite layers $\frac{1}{4}$" thick and spaced 1" apart. The grooves of the cross-beds are composed of orange, porous calcareous dolomite.

In some of the outcrops the laminae show high angles of curvature; in others they show low angles. The outcrop in the southeast corner of section 2 31N-3E, along Highway 49 at the entrance to Bowes farm shows laminae dip-angles up to 15 degrees to the southeast. The outcrop just northwest of the creek ford in Brushy Creek near the section line between sections 15 and 16 shows the laminae to dip up to 20 degrees to the south.

According to SHROCK (1948, p. 248, figure 213), limestones exhibiting cross-lamination are clearly of detrital origin since granular sediments are required for the developement of the structure. Recrystallization of the rocks may obliterate the outlines of the individual detrital particles, but weathered surfaces may show the inclined forset laminae.

d. Solution hollows

Solution hollows in the area range from small holes formed from the weathering of calcite-filled vugs to large massive caves. The typical hollows which develop at the top of Derby-Doerun beds are described in the section on lithology and thickness of Unit 3.

Hollows measuring from one to three feet in diameter occur at the following localities:

(1) on the side of the hill just up from the old road in C-W$\frac{1}{2}$ 26 31N-3E,

(2) on the bluff along Crane Pond Creek at C-N$\frac{1}{2}$-SE$\frac{1}{4}$ 35 31N-3E (on the land grant boundary), and

(3) on the bluff in C-E$\frac{1}{2}$ 10 31N-3E.

Massive hollows or caves occur at the following localities:

(1) directly along the east side of Crane Pond Creek in bluff at C-S$\frac{1}{2}$-S$\frac{1}{2}$ 26 31N-4E,

(2) on hill at NW$\frac{1}{4}$-SE$\frac{1}{4}$ 10 31N-3E (claimed by natives to be an old Jesse James hide out),

(3) on the north side of the hill along Bear Branch Road just inside of Reynolds County (this is a cave), and

(4) on the bluff in C-3 31N-3E.

Large protruding ledges forming shelters occur near the top of the bluff (Derby-Doerun, Section I) in C-S$\frac{1}{2}$-NW$\frac{1}{4}$ 15 31N-3E, and in places along the bluff to the north.

For description of the very peculiar solution structure which occurs in the Derby-Doerun formation refer to "Lithology and thickness" under Unit 3. Tafoni-type weathering hollows were mentioned under the same heading and pictured on figures 21 and 22.

V. ECONOMIC RAW MATERIALS

1. Metallic

a. Lead

Galena-bearing dolomite occurs on the dumps at the old Annapolis Lead Mine (see figures 38 and 39) at SE$\frac{1}{2}$ 14 31N-4E.

Residents of Annapolis have found similar material on the hill in SW$\frac{1}{4}$ 11 31N-3E. The ore, they claim, was probably stored in this locality during the Civil War and was never recovered. Since the locality is so close to the Annapolis Lead Mine, it seems more probable that it was stored here recently and originally came from the mine.

Residents claim that lead ore occurs at depth on the hill south of Annapolis in SW$\frac{1}{4}$ 23 31N-3E and below Big Creek in SW$\frac{1}{4}$ 24 31N-3E. These rumors stem from the fact that the St. Joseph Lead Company did extensive drilling in the hills and valleys along Big Creek a few years ago.

Elmer Robinson, owner of the grist mill, claims that galena occurs in the dolomite below the creek ford in C-W$\frac{1}{2}$-E$\frac{1}{2}$ 15 31N-3E.

A 70' uncovered, water-filled prospect shaft occurs along Richland Creek on the hill side in NE$\frac{1}{4}$-SE$\frac{1}{4}$ 5 31N-3E. The dolomite on the outcrops does not contain galena.

The covered, water-filled Annapolis Lead Mine shaft is 450' deep. The working level was at 440'. According to Charlie

Ivestor, former employee at the mine, the ore body occurred in the sediments and lapped on to the nearby porphyry knobs.

The rock on the dumps consists of sandstone (Lamotte) and dolomite. Galena and marcasite occur as bedded disseminations in the dolomites (see figure 38).

The lead deposits around Annapolis occur in a manner similar to the deposits to the north around Flat River and Fredericktown. That is, the ore bodies occur in the lower carbonates and lap onto nearby igneous knobs. The galena occurs generally as sheets or as disseminations which are parallel to the bedding.

Various theories have been proposed regarding the origin of these deposits. The three main theories include the following:

1. Lead derived from the Precambrian igneous rocks and deposited syngenetically with, or epigenetically into, the carbonates, with or without redistribution by meteoric waters after deposition. (These are syngenetic and epigenetic supergene theories by BUCKLEY (1909) and others).
2. Introduction of lead into pre-existing carbonates by hot magmatic solutions (epigenetic hypogene theory by TARR (1936) and others).
3. Lead introduced into the ocean by volcanic exhalations followed by deposition with the carbonates (syngenetic hypogene theory by AMSTUTZ (1958a, 1958b, 1959a, 1959b).

The big question here is whether the lead came from the Precambrian igneous rocks, or as ascending hot solutions or gases from an unseen igneous source.

Figure 38. Hand specimen with galena in dolomite taken from the dumps at the old Annapolis Lead Mine. Note the bedded nature of the vugs and the galena. Galena occurs in many of the vugs and as bedded disseminations.

Figure 39. View from the Mine Hollow looking east toward the old Annapolis Lead Mine area.

BUCKLEY (1909, p. 209) states the following:

> ...investigations made by J. D. Robertson, formerly of this Bureau, show that the granite contains an average of 0.00219% of lead and an average of 0.0021% of zinc; the rhyolite 0.00502% of lead and 0.0148% of zinc....The diabase dykes appear to be more strongly mineralized than either the granite or rhyolite....Provided these igneous rocks contain uniformly 0.002% of lead, the removal of a thickness of 1400' over one square mile of area would liberate approximately 68,000 short tons of lead."

BUCKLEY (1909, p. 235) believes that much of the lead, as it occurs today (in horizontal sheets and disseminations), is due to redistribution by descending meteoric solutions.

The main objection that was raised against this theory is that the enormous amount of lead which occurs could hardly have been derived from the Precambrian igneous rocks.

The second hypothesis to be considered is that of TARR'S (1936) in which he puts forth his ideas relating the deposits to magmatic solutions. TARR states that the source of the metals was a magma that occurred probably within several thousand feet of the surface, posibly one under each of the separate districts. The lead is believed to have come in largely as the chloride, and to have reacted with hydrogen sulfide and deposited lead sulfide. The paragenesis of the ores shows that the marcasite was deposited first, followed by cobalt, nickel, copper, and zinc sulfides, with galena normally last. According to TARR (1936), the galena occurs dominantly in dolomite, replacing all materials and filling cavities. It developed in any place where the lead solution found hydrogen sulfide.

As LINDGREN (1933, p. 441) states, "one of the strongest arguments against this view is that the ores have never been traced in depth."

AMSTUTZ (1958b, p. 1528), in proposing a syngenetic hypogene theory, states:

> ...the syngenetic nature is mostly shown by the pre- and syndiagenetic sedimentary fabrics which were analyzed in detail, and by the lack of replacement criteria. It brings the ore fluid in from below as hydrothermal solutions which reached the surface and dumped their mineral wealth into the ocean as submarine exhalations....Like other stable shield areas, the Middle West shows frequent rejuvenation of Precambrian polygonal fracture systems which have served as channelways for the gradually decreasing degassing of the earth, leading to mineralizations at least through Paleozoic times, and thus over much longer periods of time than in orogenic belts.

According to AMSTUTZ (1958a, p. 237):

> ...criteria for syngenetic deposition are abundant. In the sandstones at the base of the Paleozoic Series the galena,,marcasite, chalcopyrite, siegenite, etc. contain sand grains with no replacement features...criteria against epigenetic replacement are: the absence of corroded crystals; the presence of larger idiomorphic carbonates inside the sulfides; the abundance of angular breccias with only rare traces of corrosion...

AMSTUTZ (1958a, p. 237) states that:

> brecciation is ...abundant both in the basement rocks and the Paleozoic sediments. Breccias have, locally, been cemented syngenetically by ore minerals. There is often a gradual transition from contortions of non- or partly consolidated sediments to post-diagenetic brecciation.

In a recent paper on syngenesis and epigenesis, AMSTUTZ (1959a) gives more detailed criteria for the original syngenetic depositional nature of the ore textures. In a paper on zoning (1959b) he shows that fewer assumptions are involved in a syngenetic explanation of the zones in the Mississippi Valley type deposits.

According to the same author (1958a, p. 237) "exploration should be based on the assumption that the areas with late Precambrian and Paleozoic volcanic or fumarolic activity underlay areas of strongest mineralization."

b. Manganese

Fragments cemented and covered with manganese oxides occur in several places in the area.

One locality is at the Highway F-Highway C crossing at Minimum. The occurrence consists of two six inch masses of partly consolidated residuum with 1/8" coatings of manganese oxides. GRAWE (1943, p. 46) describes a similar occurrence about one mile west of this locality along Highway C. According to GRAWE, analysis showed the material to contain 1.31 percent Mn and 0.16 percent Co.

Abundant chert float covered by manganese oxide was observed in the gully along the hill on the east side of Highway F at SE¼-NE¼ 23 31N-4E.

None of these manganese deposits is believed to be of economic value at the present time.

c. Iron

Thin section study reveals that small quantities of magnetite and hematite occur in most of the felsites. Boulders with limonite and chert were observed at one locality.

Several natives claim that an old iron mine occurs on the hill near the N½-SE¼ 26 31N-4E. This mine could not be located. It is uncertain whether the ore occurs in the porphyry or in the residuum.

Boulders with limonite and chert occur along the hill side in $W\frac{1}{2}$-$NE\frac{1}{4}$ 9 31N-4E. Three small prospect pits have been dug in this area.

2. Non-metallic

a. Building stone

Porphyry, dolomite and sandstones have been quarried in the past for building and paving purposes. None of the quarries are presently in operation.

Porphyry:

Nine quarries occur in the red and reddish brown porphyry. One quarry occurs in the black Annapolis porphyry.

Eight of the quarries are located east of Annapolis along the old road in section 20 31N-4E, which begins at Highway F and follows the ridges for about two miles. The rock contains abundant quartz, and feldspar phenocrysts. The porphyry from these quarries has been used as veneer for many of the buildings in and around Annapolis. It also has been used for fence walls.

According to HAWORTH (1895) and ROBERTSON (1949), a quarry is located south of Annapolis just south of the crest of the knob in SW¼-SE¼ 22 31N-3E. The rock from this quarry has been used for paving blocks.

The quarry in the black Annapolis porphyry known as the May Quarry is located on the porphyry knob just east of Annapolis. The quarry is on the hill just southeast of the road in C-S½-S½-SW¼ 14 31N-3E.

Dolomite:

Flaggy bedded dolomite from Unit 2 has been used in several places around Annapolis for walks. The residents claim that an old quarry is located along the bluff overlooking Big Creek near the center of section 10.

Sandstone:

Several sandstone pits occur at the top of the hill in C-NE¼ 29 31N-4E, where large thick slabs of Roubidoux (?) sandstone have been recovered from the residuum. One triangular shaped pit measures 30' on the side and is 6' deep. Four smaller pits measure 10' to 15' in diameter.

Residents in the area state that the sandstone from these pits was used as veneer for several recently built school houses.

b. Agricultural limestone

Dolomite for agricultural purposes has been quarried at numerous localities throughout the area. Most of the quarries occur in beds of Unit 4. The friable nature of this rock makes it readily amenable to crushing. Only one quarry is presently in operation. This is the Duncan Brothers Quarry. The quarry is located at Vulcan, on the hill on the east side of Big Creek in the southeast corner of section 36 31N-3E.

The following is a list of localities at which agricultural limestone has been quarried:

1. along the west side of the road on the hill in C-NE¼-NW¼ 22 31N-3E,
2. in west fork of the Mine Hollow in C-W½-W½-E½ 14 31N-3E,
3. west side of road in C-E½-NW¼ 33 31N-3E,

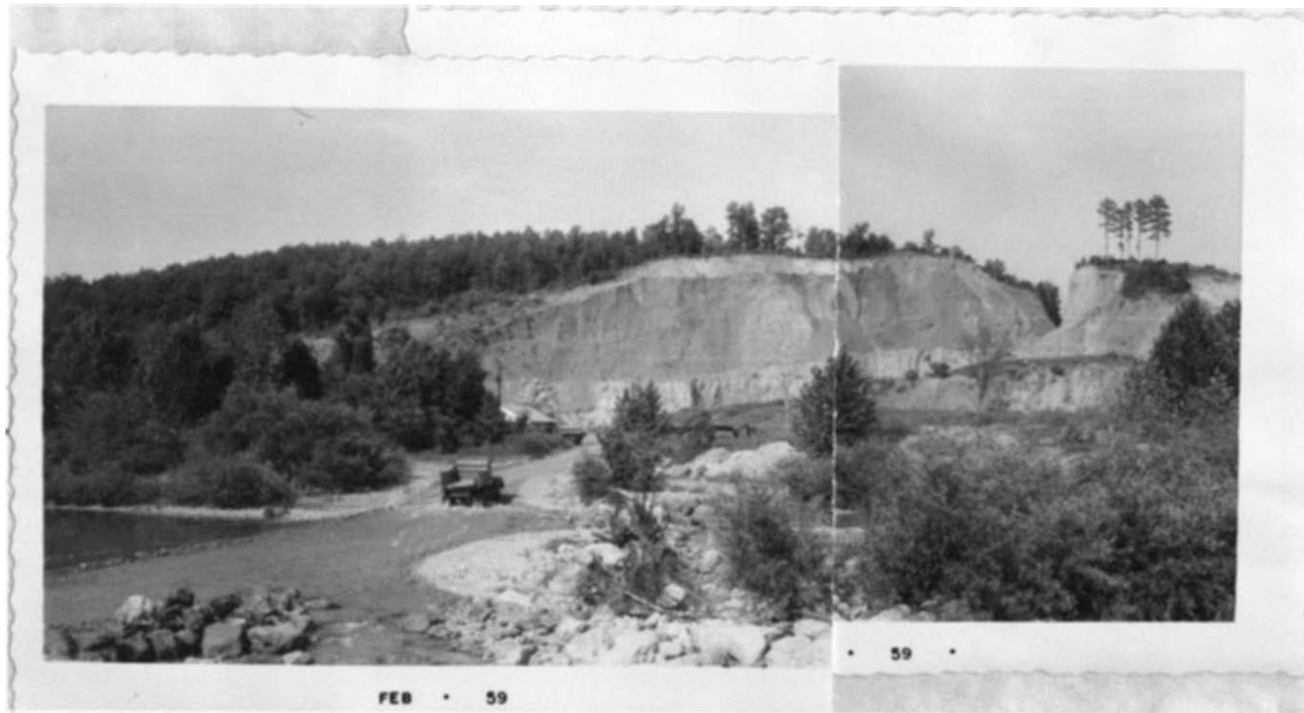


Figure 40. View from the west side of Big Creek looking northeast towards Duncan's agricultural limestone quarry in the extreme southeast corner of section 36 31N-3E. "Agricultural limestone" is quarried here, which is actually Unit 4 dolomite.

4. on hill side along east side of Sulfur Creek in C-W½-NW¼-SE¼ 9 31N-4E,

5. on south side of hill in C-W½-W- 26 31N-4E,

6. on north side of hill along Brush Creek in C-E½-NW¼ 34 31N-4E, and

7. on east side of Highway 49 in C-W½-E½-E½ 15 31N-3E.

Localities which are believed to contain appreciable amounts of dolomite suitable for crushing are as follows:

1. hill in N½-SE¼ 36 31N-4E,

2. hill in C-E½-W½ 14 31N-4E, and

3. hill about one and one-half miles northwest of Duncan's quarry at join of sections 25, 26, 35, and 36 31N-3E.

VI. SUMMARY

Outcrops in the thesis area show only igneous and sedimentary rocks. No metamorphic rocks were observed or reported in drill holes. The sedimentary rocks lie unconformably on the igneous rocks.

The igneous rocks are distributed at the surface in the following manner: (1) in the eastern portion of the area exposures occur on the hills along Crane Pond Creek and have a linear trend in a NNW-SSE direction, (2) in the north central portion of the area they form a large horseshoe with a radius of about one mile, (3) three igneous knobs are situated north, south, and east of Annapolis, and (4) one knob in the southwest corner of the area.

The igneous rocks include four main varieties of porphyritic rhyolite and one small occurrence of diabase. The rhyolites are extrusives. The diabase may form part of a sill or dike and intrudes the rhyolite.

The four varieties of porphyritic rhyolite include the following: (1) black porphyritic rhyolite, (2) brittle, purplish black rhyolite, (3) reddish brown porphyritic rhyolite with large feldspar phenocrysts, and (4) reddish brown porphyritic rhyolite with pronounced flowage.

The sequence of these varieties has been determined on several individual knobs. The sequence over the entire area is uncertain.

The sedimentary rocks are distributed along the creeks and valleys and consist predominantly of dolomites. Dips up to 20 degrees occur where they lap on the igneous knobs.

The sedimentary rocks have been subdivided into four lithologic units.

Unit 1 consists of massive beds of coarse-grained, vuggy, glauconitic dolomite with green shale in places. The rocks of this unit have a typical "Bonneterre" appearance. Unit 2 consists of thin to massive beds of fine to medium grained dolomite. Wavy flaggy beds with large calcite vugs characterize this unit. Unit 3 consists of typical massive beds of the Derby-Doerun formation. The beds mapped as Derby-Doerun include only those beds which are very similar to the massive Derby-Doerun beds occurring along Highway 32 in West Elvins near the Derby-Doerun type section. Unit 4 consists of massive beds of fine to medium-grained dolomite with quartz druse.

Unit 1 underlies Unit 4. Unit 1 underlies, overlies, and grades laterally into Unit 2. It grades laterally into Unit 3. The Unit 3 beds (massive Derby-Doerun beds) are believed to form the lower portion of Unit 4 (see figure 15).

It is believed that DAKE considered the Unit 1 beds which occur north and south of Annapolis as belonging to the Bonneterre formation and the overlying Unit 4 beds as belonging to the Potosi formation. Results from insoluble residues from samples taken around Annapolis show that the beds on both sides of the Unit 1-Unit 4 contact belong to the Derby-Doerun formation. The contact which divides the Unit 1 and Unit 4 lithologies occurs in various places in the eastern portion of the area along Crane Pond Creek. Results from samples of the rock with Unit 1 type of lithology in the northeast portion of the area have been placed in the middle Bonneterre (?).

Structures in the igneous rocks include massive flows, primary flow layers, joints, two normal faults and one diabase intrusion. The diabase intrudes porphyritic rhyolite.

A definite pattern for the joints occurs in the horseshoe shaped igneous area in the north central portion of the area.

Structures in the sedimentary rocks include beds dipping quaquaversally away from igneous highs, joints, cross-bedding, and solution hollows.

Economic raw materials include galena, sedimentary iron and manganese minerals, building stone and agricultural limestone (dolomite).

VII. Conclusions

Conclusions regarding the relations of the sedimentary rocks to known Missouri formations are presented here. Conclusions regarding the sequence of the porphyritic rhyolites over the entire area, which would ordinarily be considered here are not presented. It is felt that more field and laboratory work will be necessary in order to determine whether the rhyolites of similar varieties from different knobs actually constitute the same flows.

Massive Derby-Doerun beds occur in the area. These beds form the lower portion of Unit 4. They grade laterally into massive coarse-grained beds of Unit 1.

Insoluble residue studies have placed the beds on both sides of the Unit 1-Unit 4 contact in the Derby-Doerun formation.

DAKE considered that a Bonneterre-Potosi contact occurs in the Annapolis area. It is believed that DAKE considered the Unit 1 beds as belonging to the Bonneterre formation and the Unit 4 beds as belonging to the Potosi formation.

Since the massive beds which have been identified as Derby-Doerun occur in the lower portion of Unit 4, it is concluded that the lower portion, at least, of Unit 4 does not belong to the Potosi formation. Since the massive Derby-Doerun beds are believed to grade laterally into massive coarse-grained beds of Unit 1, it is concluded that these

Unit 1 beds, at least, do not belong in the Bonneterre formation. In addition, St. Joseph Lead Company well logs, and well logs at the Missouri Geological Survey do not show the Bonneterre formation to come to the surface in the Annapolis area.

Just how much of Unit 4 belongs to the Derby-Doerun formation (i.e., the upper contact of the Derby-Doerun formation) is uncertain. This is similarly the case with regard to Unit 1 and Unit 2 beds (i.e., the lower contact of the Derby-Doerun formation).

Insoluble residue studies from samples taken from Unit 1 beds in the northeast portion of the area have placed these beds in the middle Bonneterre (?). Since the Unit 1-Unit 4 contact occurs in this portion of the area, the Unit 1 beds should belong to the Derby-Doerun formation in order to keep the relations consistent.

These conclusions hinge on whether massive Derby-Doerun beds have been correctly identified by this writer, and the insoluble residue studies and well logs around Annapolis are correct. Assuming that they are correct, then an unconformity between the Bonneterre and Potosi formations in the Annapolis area, as postulated by DAKE, may be considered to be non-existant.

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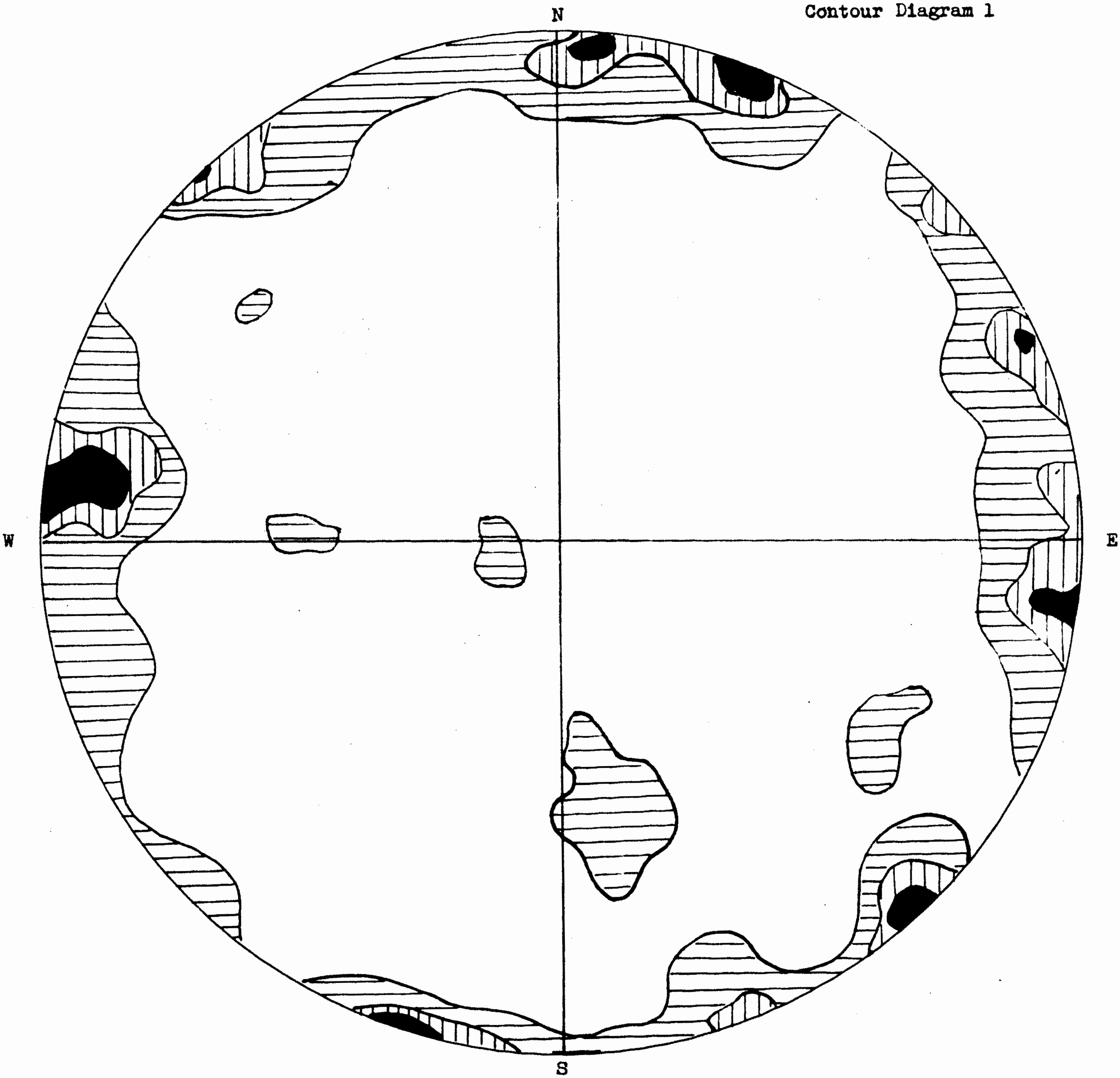
VITA

Richard Albert Zimmermann was born in Long Island City, New York, on March 11, 1930. He attended elementary school and high school in Springfield, Massachusetts. In 1948 he graduated from the Technical High School. Following graduation he enlisted in the Armed Forces, serving with the 8th and 15th Air Forces as Sergeant and was honorably discharged on July 6, 1952. In September 1953 he enrolled at the Missouri School of Mines and Metallurgy. On May 30, 1957, he received his Bachelor of Science degree in Mining Engineering with a Geology option.

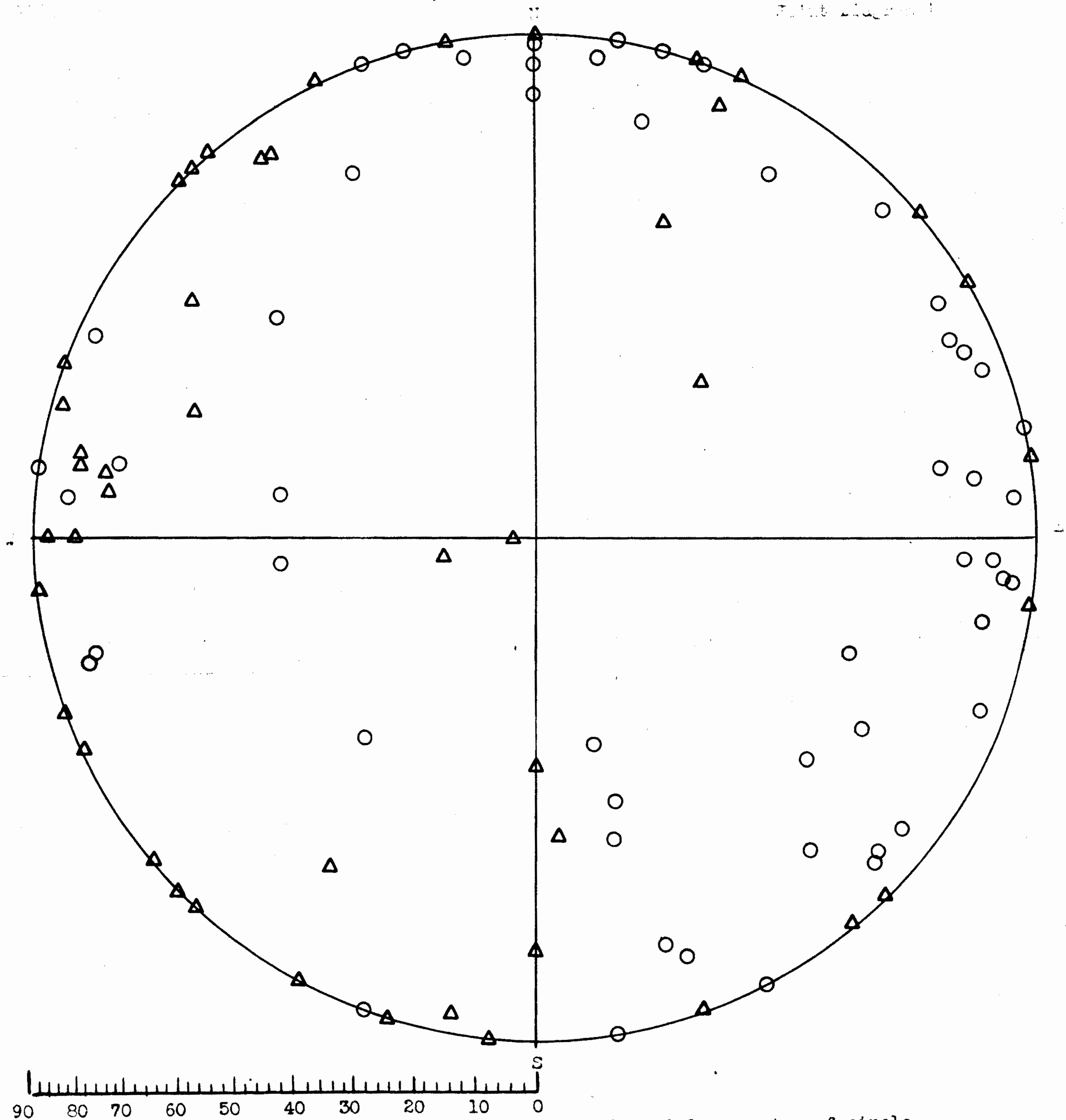
The following summer he did the field work for his thesis around Annapolis, Missouri, with financial assistance from the Missouri Geological Survey. The thesis is in partial fulfilment for the Master of Science Degree, Geology Major.

Contour Diagram 1



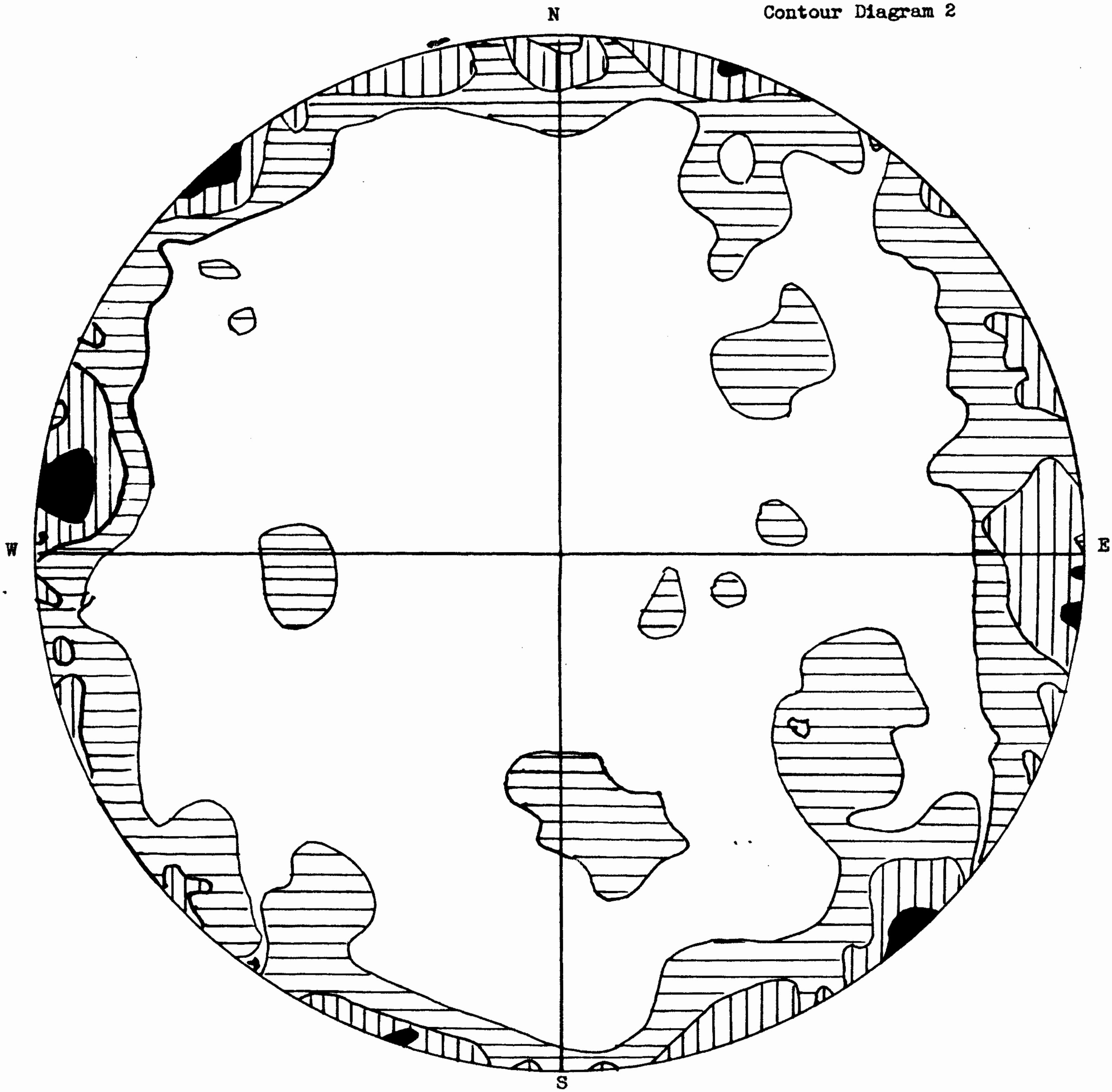
Contour diagram of 101 joints in U shaped igneous area in north central portion of area. See point diagram 1 for points.

0-2% 2-4% 4-6% 6-8%



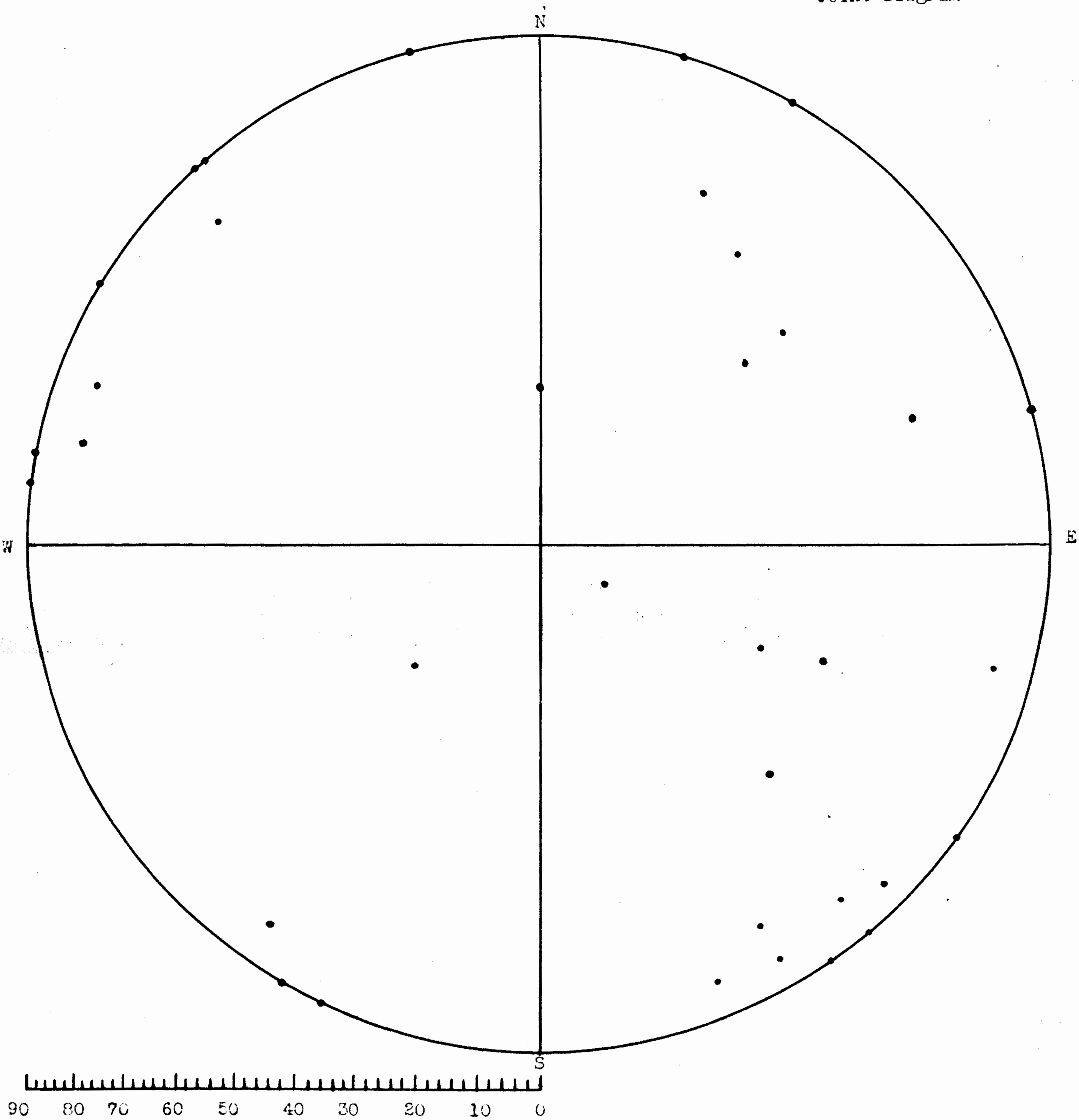
Scale used to plot poles of joints. Dip of joints plotted from center of circle.
Point diagram of 101 joints in U shaped igneous area in north central portion of area.
○ Points of joints from Grassy and Stony Mountains (Includes sections 12, 13 & 24 T31N-R3E, and section 19 T31N-R4E).
△ Points of joints in unnamed knobs on east leg of U (Includes sections 8, 9, 16, 17, 20 & 21 T31N-R4E).

Contour Diagram 2

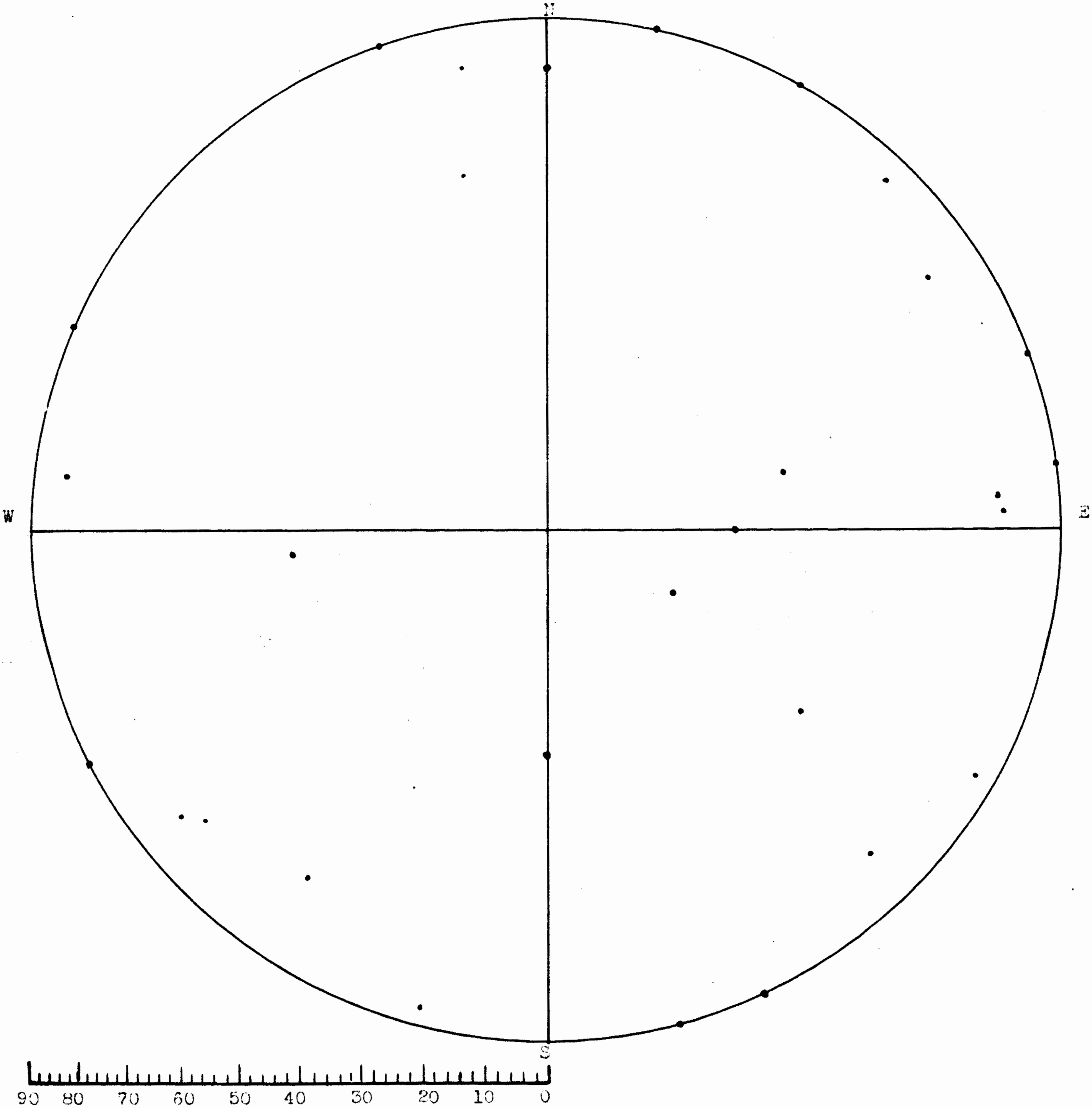


Contour diagram of 165 joints in igneous rocks from entire area. See joint diagram 4 for joints.

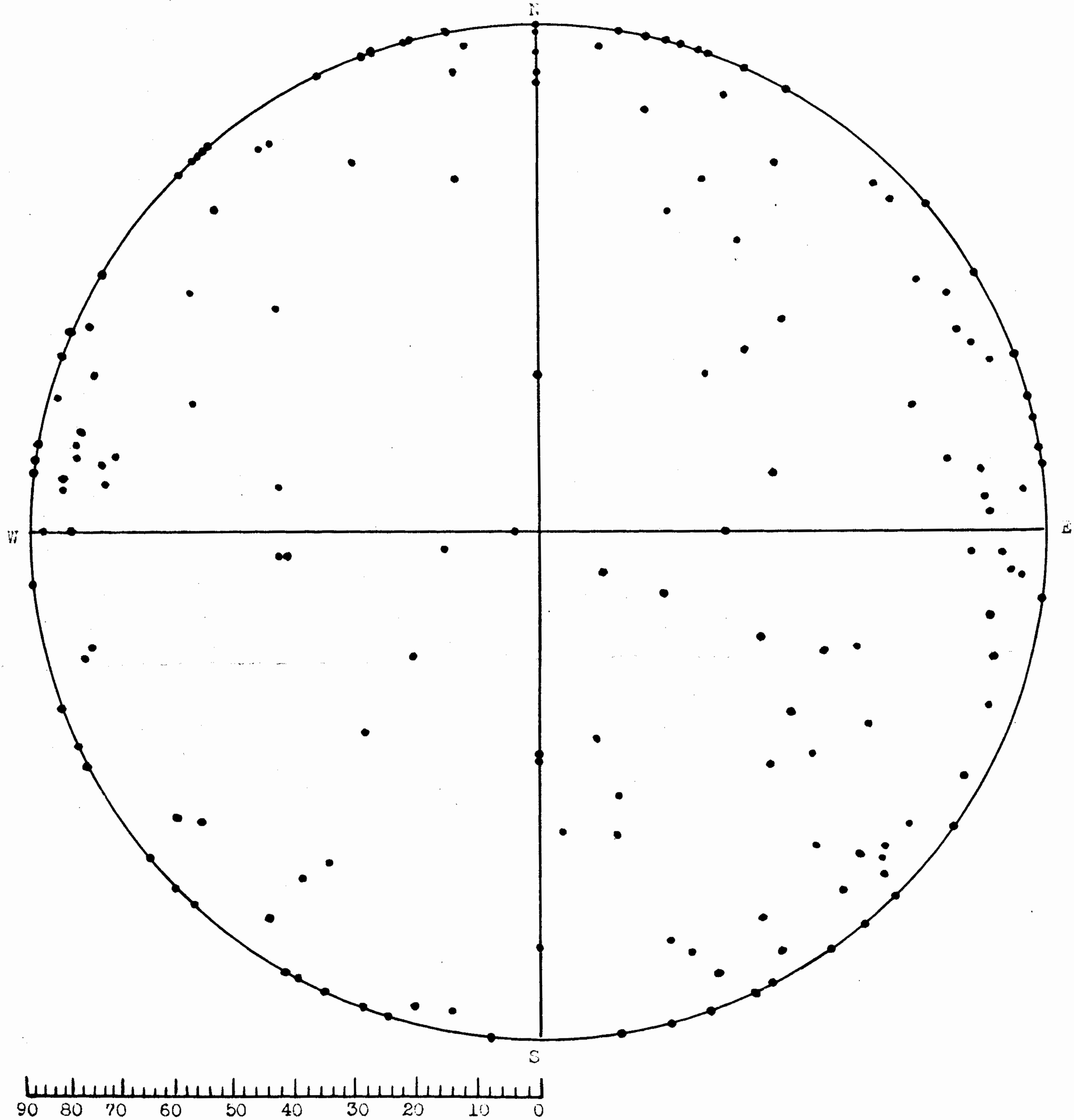
Joint Diagram 2



Scale used to plot poles of joints. Dip of joints plotted from center of circle.
Point diagram of 35 joints in igneous rocks along Crane Pond Creek (Includes sections 10, 11, 14, 23 & 26 T31N-R4E).

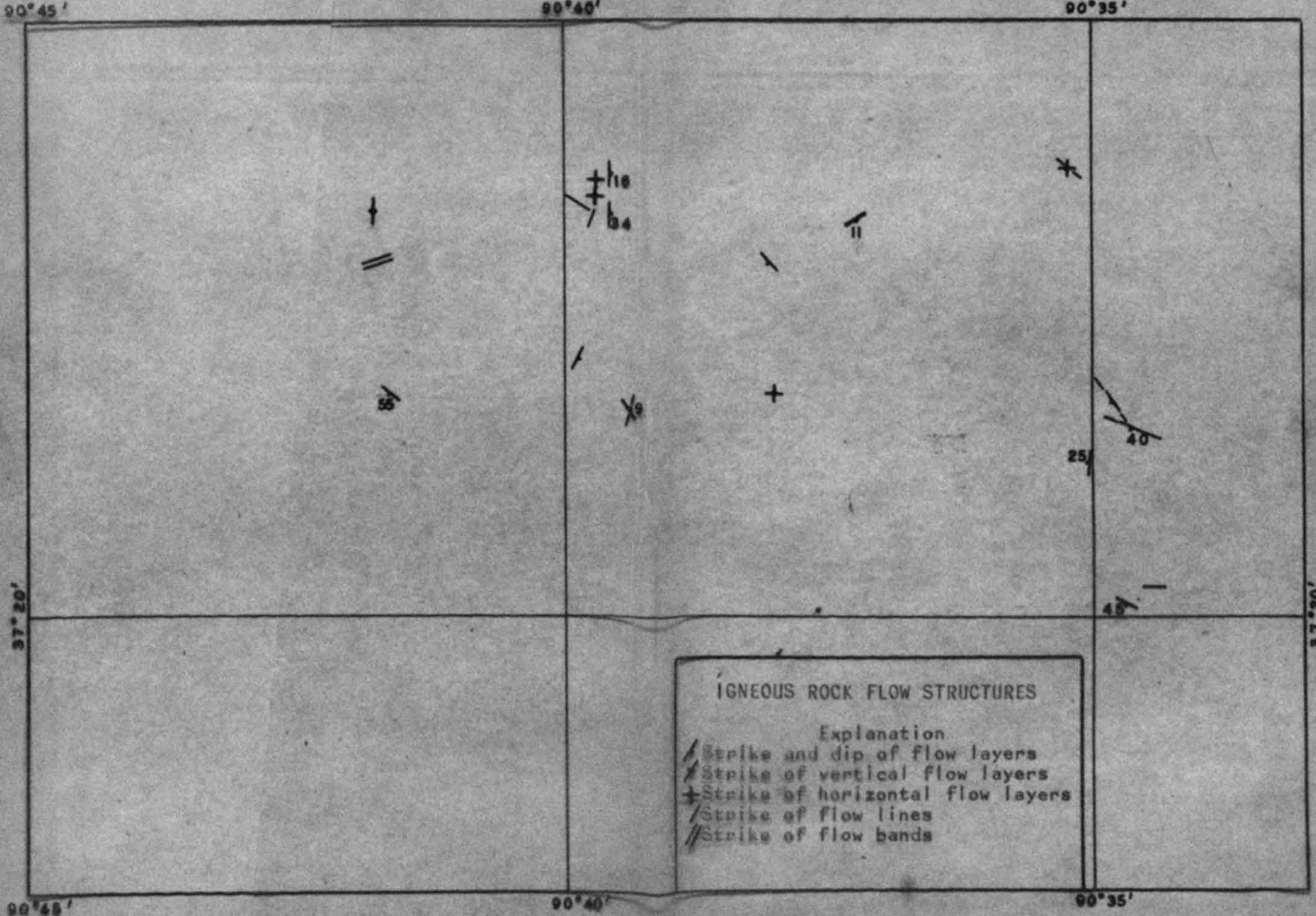


Scale used to plot poles of joints. Dip of joints plotted from center of circle. Point diagram of 29 joints in igneous rocks around Annapolis and in the southwest portion of the area (Includes sections 10, 14, 15, 22 & 27 T31N-R3E, and section 4 T30N-R3E).



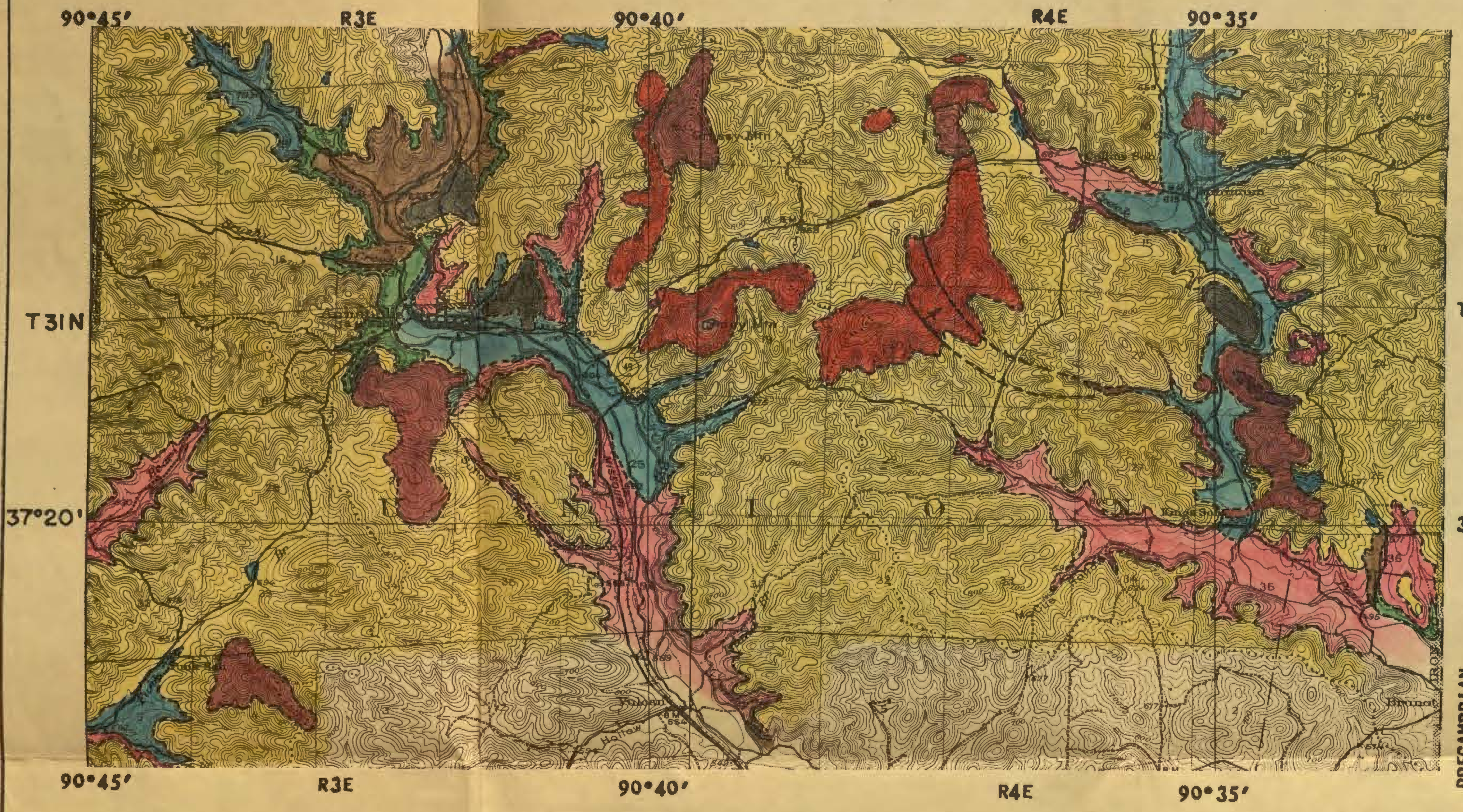
Scale used to plot poles of joints. Dip of joints plotted from center of circle.
Point diagram of 165 joints in igneous rocks from entire area.

OVERLAY I


90°45′
90°40′
90°35′
37°20′
18
34
11
55
9
40
25
45
IGNEOUS ROCK FLOW STRUCTURES
Explanation
Strike and dip of flow layers
Strike of vertical flow layers
Strike of horizontal flow layers
Strike of flow lines
Strike of flow bands

OVERLAY 1

90°45'
90°40'
90°35'
31°20'
15
34
11
55
9
40
45
IGNEOUS ROCK FLOW STRUCTURES
Explanation
Strike and dip of flow layers
Strike of vertical flow layers
Strike of horizontal flow layers
Strike of flow lines
Strike of flow bands
90°45'
90°40'
90°35'



GEOLOGIC SYMBOLS

----Contact

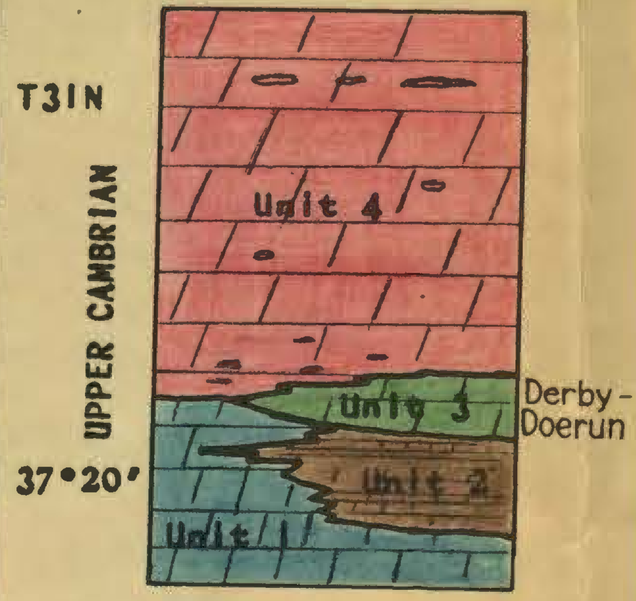
---Fault, showing direction of dip

EXPLANATION

Sedimentary Rocks

Residuum

Chert, sand, clay etc



Predominantly dolo.

Igneous Rock Types

PRECAMBRIAN

- Diabase (NE 1/4 24 31N-3E)
- Brittle, purplish black rhyolite
- Reddish brown to bluish gray porphyritic rhyolite
- Reddish brown porphyritic rhyolite
- Black porphyritic rhyolite (Annapolis felsite)

Unit 4

Massive beds of medium to fine grained, somewhat vuggy dolomite with quartz druse; large, rusty masses of thinly cellular silica with quartz druse in upper part of section. These rocks have a "Potosi" appearance.

Unit 3

Massive beds of porous, cross-bedded medium grained dolomite with small quartz druse; similar to massive bedded Derby-Doerun along Hwy 32 near West Elvins (type section) in C-SW¼ 13 T36N-R4E.

Unit 2

Thin to massive beds of fine to medium grained calcareous dolomite. Wavy, flaggy beds with large elliptical calcite vugs characterize this unit.

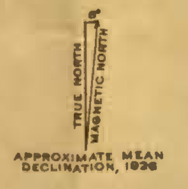
Unit 1

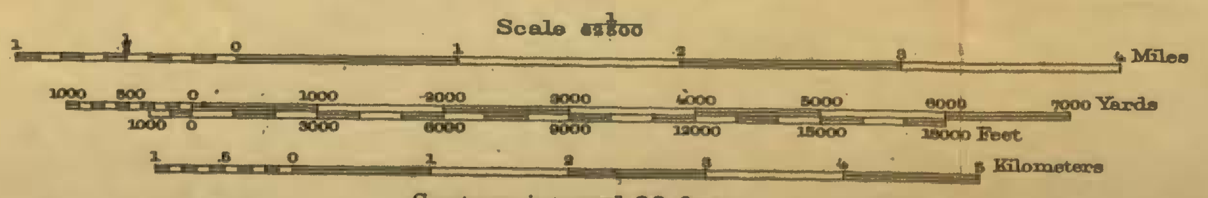
Massive beds of coarse grained, vuggy, calcareous dolomite with green shale in places. These rocks have a "Bonneterre" appearance.

Topographic base from
Des Arc, Missouri Quadrangle
Published by U.S.G.S., 1946

GEOLOGIC MAP OF ANNAPOLIS AREA

By
Richard A. Zimmermann





Contour interval 20 feet

Datum is mean sea level